Orthopedic Traumatology

An Evidence-Based Approach

Second Edition

Manish K. Sethi
William T. Obremskey
A. Alex Jahangir
Editors

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Basem Attum
Associate Editors

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Editors
Manish K. Sethi, MD
Department of Orthopedics
Vanderbilt University Medical Center
Nashville, TN, USA

A. Alex Jahangir, MD, MMHC
Department of Orthopedics
Vanderbilt University Medical Center
Nashville, TN, USA

William T. Obremskey, MD, MPH, MMHC
Department of Orthopedics
Vanderbilt University Medical Center
Nashville, TN, USA

Associate Editors
Thomas J. Iorio, BS
Department of Orthopedic Surgery
and Rehabilitation
Vanderbilt University Medical Center
Nashville, TN, USA

Basem Attum, MD, MS
Department of Orthopedic Surgery
and Rehabilitation
Vanderbilt University Medical Center
Nashville, TN, USA

Michelle S. Shen, BA
Department of Orthopedic Surgery
and Rehabilitation
Vanderbilt University Medical Center
Nashville, TN, USA

Section Editors
Mohit Bhandari, MD, PhD, FRCSC
Division of Orthopedic Surgery
McMaster University
Hamilton, ON, Canada

Michael David McKee, MD, FRCS(C)
Division of Orthopedics, Department of Surgery
St. Michael's Hospital, University of Toronto
Toronto, ON, Canada

Paul Tornetta III, MD
Department of Orthopedic Surgery
Boston Medical Center
Boston, MA, USA

Andrew H. Schmidt, MD
Department of Orthopedic Surgery
Hennepin County Medical Center

Department of Orthopedic Surgery
Unviersity of Minnesota
Minneapolis, MN, USA

Mitchel B. Harris, MD, FACS
Department of Orthopedic Surgery
Brigham and Women's Hospital
Harvard Medical School
Boston, MA, USA

Cory A. Collinge, MD
Department of Orthopedic Surgery
and Rehabilitation
Vanderbilt University Medical Center
Nashville, TN, USA

Roy Sanders, MD
University of South Florida
Department of Orthopedics
Florida Orthopedic Institute
Tampa General Hospital
Journal of Orthopedic Trauma
Tampa, FL, USA

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Foreword

When I wrote the foreword to the first edition of *Orthopedic Traumatology: An Evidence-Based Approach* in late 2011, I emphasized the progress in the orthopedic trauma community toward using, on a routine basis, the highest levels of evidence on which to base treatment decisions. The first edition of *Orthopedic Traumatology* has proven to fulfill that need as our community moves away from expert opinion in the form of standard textbook writing and toward aggregation of the highest levels of evidence. Not everything in orthopedic trauma surgery is able to be studied with randomized trials, as many injuries are of low incidence such that well-done cohort studies are going to be the highest level of evidence available on which to base our treatment decisions in the long run. However, the editors of the first edition – Drs. Sethi, Jahangir, and Obremskey – and the chapter authors provided the roadmap of level 1 and level 2 evidence for the most common conditions in orthopedic traumatology. This approach has proven to be extremely useful, with over 17,000 downloads of this compilation.

In this second edition, the editors – now Drs. Sethi, Obremskey, and Jahangir – decided to add chapters on four new conditions that are relatively common. This includes chapters on elbow fracture dislocation, hip-pelvis-femoral neck fracture combination in younger patients, mid-foot fractures, and acute infection. These chapters all represent useful additions to the compendium. All chapter authors have performed extensive and broad-reaching literature reviews to identify any high-level evidence that has been published since the first edition.

The result is a book which is very useful for teaching and, more importantly, for making individual treatment decisions and for developing protocols for use in trauma centers. These highly committed and compulsive editors and authors have done a yeoman's work in providing these collections of the highest level of evidence. I recommend this second edition with great enthusiasm, as it is the continued fulfillment of our migration toward evidence-based orthopedic trauma surgery for patient care.

Minneapolis, MN, USA — Marc Swiontkowski

Preface

As medicine makes a transition from volume to value, the need for evidence-based practice is of even greater importance. We undertook the process of creating this book to help residents, fellows, and practicing orthopedic surgeons understand the principles on which medical decisions are made and to provide them with a reference that explains the data and thought processes of leaders in orthopedic trauma patient care. Many "HOW" books are available on surgical technique. This book was designed and intended to be a "WHY" book that would help clinicians understand and make evidence-based decisions on patient care.

We thank our many chapter authors – who are thought leaders and excellent clinicians – for their astute evaluation of the literature and clear communication of treatment options.

The response and distribution of the first edition of this evidence-based book were so great that we felt compelled to provide a second edition. We hope this second edition continues the work started by the first edition to improve the knowledge depth of clinicians and the quality of care for patients.

Nashville, TN, USA

Manish K. Sethi, MD
William T. Obremskey, MD, MMHC, MPH
A. Alex Jahangir, MD, MMHC

Contents

Contributors

Moses Adebayo, MD Department of Orthopedic Surgery, Howard University, Washington, DC, USA

Obioma V. Amajoyi, MD Department of Orthopedics and Rehabilitation, University of Wisconsin-Madison, University of Wisconsin Hospital and Clinics, Madison, WI, USA

Cameron T. Atkinson, MD Arlington Orthopedic Associates, Arlington, TX, USA

Basem Attum, MD, MS Department of Orthopedic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA

Frank R. Avilucea, MD Department of Orthopedic Surgery, Division of Orthopedic Trauma, University of Cincinnati Medical Center, Cincinnati, OH, USA

Keith D. Baldwin, MD Children's Hospital of Philadelphia, Department of Orthopedics, University of Pennsylvania, Philadelphia, PA, USA

David P. Barei, MD, FRCSC Harborview Medical Center, University of Washington, Department of Orthopedics, Seattle, WA, USA

Rita E. Baumgartner, MD Department of Orthopaedic Surgery, Duke University Medical Center, Durham, NC, USA

Mohit Bhandari, MD, PhD, FRCSC Division of Orthopedic Surgery, McMaster University, Hamilton, ON, Canada

Jesse E. Bible, MD, MHS Department of Orthopedics, Penn State Milton S. Hershey Medical Center, Hershey, PA, USA

Damien G. Billow, MD Department of Orthopedics, Cleveland Clinic, Cleveland, OH, USA

Michael J. Bosse, MD Department of Orthopedic Surgery, Carolinas Medical Center, Charlotte, NC, USA

Christina L. Boulton, MD Department of Orthopedic Surgery, University of Arizona – Banner University Medical Center, Tucson, AZ, USA

Megan A. Brady, MD Iowa Methodist Medical Center, Des Moines Orthopedic Surgeons, West Des Moines, IA, USA

Richard Buckley, MD, FRCS Department of Surgery, Foothill Medical Center, University of Calgary, Calgary, AB, Canada

Peter A. Cole, MD Department of Orthopaedic Surgery, Regions Hospital, St. Paul, MN, USA

Department of Orthopaedic Surgery, University of Minnesota, Minneapolis, MN, USA

Cory A. Collinge, MD Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA

Seth A. Cooper, MD Florida Medical Clinic, Department of Orthopedic Surgery, Tampa, FL, USA

Chad M. Corrigan, MD Wesley Medical Center, University of Kansas – Wichita School of Medicine, Wichita, KS, USA

Samuel Neil Crosby Jr., MD Elite Sports Medicine and Orthopedic Center, Nashville, TN, USA

Clinton J. Devin, MD Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA

Diana G. Douleh, MD Department of Orthopedic Surgery, University of Colorado Hospital, University of Colorado, Aurora, CO, USA

Jesse M. Ehrenfeld, MD, MPH Department of Anesthesiology, Surgery, Biomedical Informatics and Health Policy, Vanderbilt University School of Medicine, Vanderbilt University Medical Center, Nashville, TN, USA

Clary J. Foote, MD Division of Orthopedic Surgery, McMaster University, Hamilton, ON, Canada

Vamshi Gajari, MBBS Department of Orthopedic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA

James L. Guyton, MD Regional One Health, University of Tennessee – Campbell Clinic, Memphis, TN, USA

Jeremy A. Hall, MD, FRCSC, MEd Division of Orthopedics, St. Michael's Hospital, Department of Surgery, University of Toronto, Toronto, ON, Canada

Mitchel B. Harris, MD, FACS Department of Orthopaedic Surgery, Harvard Medical School, Massachusetts General Hospital, Boston, MA, USA

A. Alex Jahangir, MD Department of Orthopedic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA

Andrew Jawa, MD New England Baptist Hospital, Tufts University Medical School, Boston, MA, USA

Matthew D. Karam, MD Department of Orthopedics and Rehabilitation, University of Iowa Hospitals and Clinics, Department of Orthopedics and Rehabilitation, University of Iowa, Iowa City, IA, USA

Laurence B. Kempton, MD Indiana University School of Medicine, Department of Orthopedic Surgery, IU Health Methodist Hospital, Indianapolis, IN, USA

Conor Kleweno, MD Harborview Medical Center, Department of Orthopedic Surgery, Seattle, WA, USA

University of Washington, Department of Orthopedics and Sports Medicine, Seattle, WA, USA

Adam Keith Lee, MD Department of Orthopedic Surgery, Keck School of Medicine of University of Southern California, Los Angeles, CA, USA

Michael C. Lubrano, MD, MPH Department of Anesthesia and Perioperative Care, UCSF School of Medicine, San Francisco, CA, USA

Erik A. Lund, MD Department of Orthopedics and Rehabilitation, University of Wisconsin–Madison, University of Wisconsin Hospital and Clinics, Madison, WI, USA

Michael David McKee, MD, FRCS(C) Department of Orthopaedic Surgery, University of Arizona College of Medicine–Phoenix, Phoenix, AZ, USA

Samir Mehta, MD Penn Presbyterian Medical Center, University of Pennsylvania, Department of Orthopedic Surgery, Philadelphia, PA, USA

Hassan R. Mir, MD, MBA, FACS Florida Orthopedic Institute, University of South Florida, Tampa, FL, USA

Surena Namdari, MD, MSc Rothman Institute and Department of Orthopaedic Surgery, Thomas Jefferson University, Philadelphia, PA, USA

Kevin R. O'Neill, MD, MS OrthoIndy, Inc., Indianapolis, IN, USA

Robert V. O'Toole, MD R. Adams Cowley Shock Trauma Center, University of Maryland School of Medicine Department of Orthopedics, Baltimore, MD, USA

William T. Obremskey, MD, MPH, MMHC Department of Orthopedic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA

Steven A. Olson, MD, FACS Department of Orthopaedic Surgery, Duke University Medical Center, Durham, NC, USA

Christopher D. Parks, MD Department of Orthopedics, New Hanover Regional Medical Center, Wilmington, NC, USA

Brendan M. Patterson, MD, MBA Cleveland Clinic Main Campus, Case Western Reserve University School of Medicine, Department of Orthopedic Surgery, Cleveland, OH, USA

Edward A. Perez, MD Regional One Health, University of Tennessee – Campbell Clinic, Memphis, TN, USA

Kevin D. Phelps, MD Department of Orthopedic Surgery, Carolinas Medical Center, Charlotte, NC, USA

Mark Phillips, MSc(c) Division of Orthopedic Surgery, McMaster University, Hamilton, ON, Canada

David Polga, MD Department of Orthopedic Surgery, Marshfield Clinic, Marshfield, WI, USA

Lee M. Reichel, MD Department of Surgery and Perioperative Care, Dell Medical School at The University of Texas at Austin, Austin, TX, USA

William M. Ricci, MD Hospital for Special Surgery, Weill Cornell School of Medicine, New York, NY, USA

David Ring, MD, PhD Department of Surgery and Perioperative Care, Dell Medical School at The University of Texas at Austin, Austin, TX, USA

Bill Ristevski, MD, MSc, FRCS(c), BSc Division of Orthopedics, Hamilton General Hospital, Department of Surgery, McMaster University, Hamilton, ON, Canada

Edward K. Rodriguez, MD, PhD Beth Israel Deaconess Medical Center, Department of Orthopedic Surgery, Boston, MA, USA

Harvard Medical School, Boston, MA, USA

Matthew I. Rudloff, MD Regional One Health, University of Tennessee – Campbell Clinic, Memphis, TN, USA

Scott P. Ryan, MD Department of Orthopaedics, Tufts University School of Medicine, Tufts Medical Center, Boston, MA, USA

Marlis T. Sabo, MD, MSc, FRCSC Department of Surgery, South Health Campus, Cumming School of Medicine, Calgary, AB, Canada

David W. Sanders, MD, FRCSC Department of Surgery, Victoria Hospital–LHSC, University of Western Ontario, London, ON, Canada

Roy Sanders, MD Florida Orthopedic Institute, University of South Florida, Tampa, FL, USA

Lisa K. Schroder, BSME, MBA Department of Orthopaedic Surgery, Regions Hospital, St. Paul, MN, USA

Department of Orthopaedic Surgery, University of Minnesota, Minneapolis, MN, USA

Brian L. Seeto, MD, FRCSC The CORE Institute, Phoenix, AZ, USA

Manish K. Sethi, MD Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA

Michelle S. Shen, BA Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA

Jodi Siegel, MD Department of Orthopedics, University of Massachusetts Memorial Medical Center, University of Massachusetts Medical School, Worcester, MA, USA

Clay A. Spitler, MD Department of Orthopedic Surgery, University of Mississippi Medical Center, Jackson, MS, USA

Philipp N. Streubel, MD Department of Orthopedic Surgery and Rehabilitation, University of Nebraska Medical Center, Omaha, NE, USA

Michel A. Taylor, MD, FRCSC Department of Surgery, Victoria Hospital—LHSC, University of Western Ontario, London, ON, Canada

David C. Templeman, MD University of Minnesota, Hennepin County Medical Center, Minneapolis, MN, USA

Daniel G. Tobert, MD Department of Orthopaedic Surgery, Harvard Medical School, Massachusetts General Hospital, Boston, MA, USA

Paul Tornetta III, MD Department of Orthopedic Surgery, Boston Medical Center, Boston, MA, USA

Theodoros H. Tosounidis, MD, PhD Major Trauma Centre, Leeds General Infirmary, Academic Department of Trauma and Orthopedic Surgery, University of Leeds, NIHR Leeds Biomedical Research Unit, Chapel Allerton Hospital, Leeds, UK

Samuel A. Trenner, DPM Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA

Robert T. Trousdale, MD Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, USA

Jeffry T. Watson, MD Colorado Springs Orthopedic Group, Colorado Springs, CO, USA

John C. Weinlein, MD Regional One Health, University of Tennessee – Campbell Clinic, Memphis, TN, USA

Paul S. Whiting, MD Department of Orthopedics and Rehabilitation, University of Wisconsin–Madison, University of Wisconsin Hospital and Clinics, Madison, WI, USA

Mahesh Kumar Yarlagadda, BS, MSPH Department of Orthopedic Trauma, Vanderbilt University Medical Center, Meharry Medical College, Nashville, TN, USA

Jeffrey Zhao, BA Northwestern Medicine, Northwestern University Feinberg School of Medicine, Chicago, IL, USA

Part I

Evidence-Based Medicine in Orthopedic Trauma Surgery

1 Introduction to Evidence-Based Medicine

Clary J. Foote, Mark Phillips, and Mohit Bhandari

Introduction

The science of addressing problems that confront orthopedic surgeons every day requires a rigorous methodology to guide investigation and provide valid answers. The term "evidence-based medicine" (EBM), first coined by Dr. Gordon Guyatt at McMaster University, has become the standard for clinical investigation and critical appraisal. EBM has been defined as the conscientious and judicious use of current best available evidence as the basis for surgical decisions [1–3]. Application of the evidence does not occur in isolation but rather with integration of surgical expertise and clinical circumstances, as well as with societal and patient values [4, 5] (Fig. 1.1). In addition, identifying and applying best available evidence require a comprehensive search of the literature, a critical appraisal of the validity and quality of available studies, astute consideration of the clinical situation and factors that may influence applicability, and a balanced application of valid results to the clinical problem [6].

In 2000, Marc Swiontkowski introduced the evidence-based orthopedics (EBO) section of the *Journal of Bone and Joint Surgery* (JBJS) with a focus on higher levels of evidence such as randomized controlled trials (RCTs), which recognized the deficiency of controlled studies in the orthopedic literature [7]. In 2003, the JBJS adopted EBM and the hierarchy of evidence for grading all clinical papers. Also during that year, Dr. Bhandari initiated the evidence-based orthopedic trauma section in the *Journal of Orthopaedic Trauma* (JOT) [8]. Since then, the EBO initiative has grown into a global initiative and has become the common language at international orthopedic meetings. The American Orthopedic Society has recognized and incorporated EBO for utilization into clinical guidelines [9]. Clinical practice guidelines developed by organizations such as the American Academy of Orthopaedic Surgeons (AAOS) have become a prominent driver of EBO dissemination, as these groups have adopted an evidence-based approach for providing clinical recommendations to orthopedic surgeons.

Paramount to the understanding of "best available evidence" are the concepts of hierarchy of evidence, meta-analyses, study design, and precision of results. A familiarity with these concepts will aid the orthopedic surgeon in identifying, understanding, and incorporating best evidence into their practice. We begin here with an overview of the hierarchy of surgical evidence with attention paid to study design and methodological quality. Some of the common instruments to

C. J. Foote · M. Phillips · M. Bhandari (✉)
Division of Orthopedics, McMaster University, Hamilton, ON, Canada
e-mail: bhandam@mcmaster.ca

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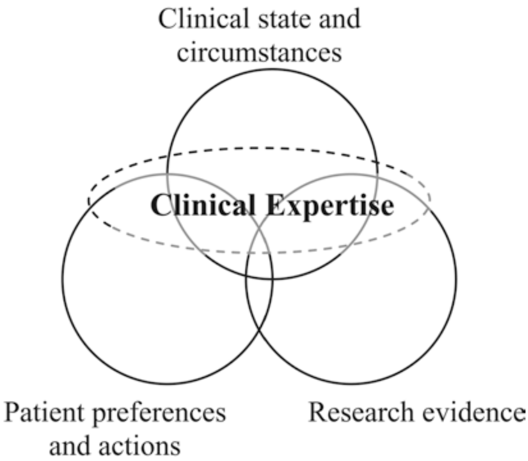

Fig. 1.1 The triumvirate of evidence-based orthopedics (EBO) to improve best practice in orthopedics (Used from Ref. [5]: with permission of John Wiley and Sons Tilburt et al.)

measure study quality are described, and we direct our readership to adjunctive educational resources. Finally, we conclude by clarifying misconceptions of EBO to reinforce its underpinning principles that help the reader interpret the surgical evidence presented in this text.

Hierarchy of Research Studies

To understand the concept of best evidence, a surgeon must first be knowledgeable about the hierarchy of surgical evidence. The hierarchy can be thought of as a classification system to provide a common language for communication and a basis for review of available evidence. Research studies range from very high quality to low quality, which are largely based on the study design and methodological quality [10]. In general, high-quality studies minimize bias and thus increase our confidence in the validity of results. Bias can be defined as systematic error in a research study that impacts outcome such that it differs from the truth [11]. There are several available systems to formulate the level of evidence of a given study. The Oxford Centre for Evidence-Based Medicine has published hierarchies for therapeutic, prognostic, harm, prevalence, and economic analyses [12]. For each of aforementioned subcategories, there is a hierarchy of evidence with unique clinical significance [13, 14]. JBJS has incorporated the Oxford System in order to develop a hierarchy for orthopedic studies (Table 1.1). For the purposes of this text, when we refer to the "hierarchy" or "level of evidence," we will be referring to this table.

In orthopedic traumatology, therapeutic studies are of central importance. For instance, they may tell us the revision surgery rates of dynamic hip screws versus cancellous screws for the treatment of femoral neck fractures [15]. When evaluating a study of a surgical or therapeutic intervention, one must identify the study design as an initial step to identify best evidence [16]. The highest level of evidence lies in RCTs and systematic reviews or meta-analyses of high-quality RCTs [17, 18]. These are referred to as level I trials [2]. The process of randomization is the best research tool to minimize bias by distributing known and unknown prognostic variables uniformly between treatment groups [19, 20]. Available evidence suggests that non-randomized studies tend to overestimate [21] or underestimate [22] treatment effects. Systematic reviews of RCTs use rigorous methodology to improve sample size and precision of study results and are therefore considered the highest level of evidence when reviewed studies are of sufficient methodological quality [12, 23]. Reviews may statistically combine results (meta-analyses) when trial reporting allows or provide a qualitative overview of the results of included studies (systematic reviews) [24]. Additionally, reviews may indirectly compare pooled results (network meta-analyses) across multiple interventions that have not been directly compared within an RCT. For example, if there are two RCTs, one comparing treatment A to placebo and one comparing treatment B to placebo, an indirect comparison can be made between treatment A and treatment B [25]. Non-randomized prospective studies such as cohort studies (also known as prospective comparative studies) provide weaker empirical evidence, as they are prone to several biases [22]. For instance, treatment allocation is uncontrolled, and therefore treatment cohorts may differ in prognosis from the outset due to selection bias

Table 1.1 Levels of evidence for primary research question[a,b]

Study type	Question	Level I	Level II	Level III	Level IV	Level V
Diagnostic – investigating a diagnostic test	Is this (early detection) test worthwhile?	Randomized controlled trial	Prospective[c] cohort[d] study	Retrospective[e] cohort[d] study Case–control[f] study	Case series	Mechanism-based reasoning
	Is this diagnostic or monitoring test accurate?	Testing of previously developed diagnostic criteria (consecutive patients with consistently applied reference standard and blinding)	Development of diagnostic criteria (consecutive patients with consistently applied reference standard and blinding)	Nonconsecutive patients No consistently applied reference standard	Poor or nonindependent reference standard	Mechanism-based reasoning
Prognostic – investigating the effect of a patient characteristic on the outcome of a disease	What is the natural history of the condition?	Inception[c] cohort study (all patients enrolled at an early, uniform point in the course of their disease)	Prospective[c] cohort[d] study (patients enrolled at different points in their disease) Control arm of randomized trial	Retrospective[e] cohort[d] study Case–control[f] study	Case series	Mechanism-based reasoning
Therapeutic – investigating the results of a treatment	Does this treatment help? What are the harms?[g]	Randomized controlled trial	Prospective[c] cohort[d] study Observational study with dramatic effect	Retrospective[e] cohort[d] study Case–control[f] study	Case series Historically controlled study	Mechanism-based reasoning
Economic	Does the intervention offer good value for dollars spent?	Computer simulation model (Monte Carlo simulation, Markov model) with inputs derived from level I studies, lifetime time duration, outcomes expressed in dollars per quality-adjusted life years (QALYs), and uncertainty examined using probabilistic sensitivity analyses	Computer simulation model (Monte Carlo simulation, Markov model) with inputs derived from level II studies, lifetime time duration, outcomes expressed in dollars per QALYs, and uncertainty examined using probabilistic sensitivity analyses	Computer simulation model (Markov model) with inputs derived from level II studies, relevant time horizon, less than lifetime, outcomes expressed in dollars per QALYs, and stochastic multilevel sensitivity analyses	Decision tree over the short time horizon with input data from original level II and III studies and uncertainty is examined by univariate sensitivity analyses	Decision tree over the short time horizon with input data informed by prior economic evaluation and uncertainty is examined by univariate sensitivity analyses

Used from Ref. [71]: with permission of Wolters Kluwer Health Inc. from Marx et al.

(continued)

Table 1.1 (continued)

[a]This chart was adapted from OCEBM Levels of Evidence Working Group, "The Oxford 2011 Levels of Evidence," Oxford Centre for Evidence-Based Medicine, http://www.cebm.net/index.aspx?o=5653. OCEBM Table of Evidence Working Group = Jeremy Howick, Iain Chalmers (James Lind Library), Paul Glasziou, Trish Greenhalgh, Carl Heneghan, Alessandro Liberati, Ivan Moschetti, Bob Phillips, Hazel Thornton, Olive Goddard and Mary Hodgkinson. A glossary of terms can be found here: http://www.cebm.net/glossary/

[b]Level I through IV studies may be graded downward on the basis of study quality, imprecision, indirectness, or inconsistency between studies or because the effect size is very small; these studies may be graded upward if there is a dramatic effect size. For example, a high-quality randomized controlled trial (RCT) should have ≥80% follow-up, blinding, and proper randomization. The level of evidence assigned to systematic reviews reflects the ranking of studies included in the review (i.e., a systematic review of level II studies is level II). A complete assessment of the quality of individual studies requires critical appraisal of all aspects of study design

[c]Investigators formulated the study question before the first patient was enrolled

[d]In these studies, "cohort" refers to a nonrandomized comparative study. For therapeutic studies, patients treated one way (e.g., cemented hip prosthesis) are compared with those treated differently (e.g., cementless hip prosthesis)

[e]Investigators formulated the study question after the first patient was enrolled

[f]Patients identified for the study on the basis of their outcome (e.g., failed total hip arthroplasty), called "cases," are compared with those who did not have the outcome (e.g., successful total hip arthroplasty), called "controls"

[g]Sufficient numbers are required to rule out a common harm (affects >20% of participants). For long-term harms, follow-up duration must be sufficient

Table 1.2 Definitions of bias types in therapeutic studies

Types of biases	Definition
Selection bias	Treatment groups differ in measured and unmeasured characteristics and therefore have differential prognosis due to systematic error in creating intervention groups [33]
Recall bias	Patients who experience an adverse outcome are more likely to recall exposure than patients who do not sustain an adverse outcome [28, 72]
Detection bias	Biased assessment of outcome. May be influenced by such things as prior knowledge of treatment allocation or lack of independent affiliation within a trial [26]
Performance bias	Systematic differences in the care provided to cohorts are independent of the intervention being evaluated [26, 73]
Attrition bias	Occurs when those that drop out of a study are systematically different from those that remain. Thus, final cohorts may not be representative of original group assignments [2, 74]
Expertise bias	Occurs when a surgeon involved in a trial has differential expertise (and/or convictions) with regard to procedures in a trial where trial outcomes may be impacted by surgeon competency and/or beliefs rather than interventional efficacy [75]

(Table 1.2) [26]. Retrospective case–control studies assess past characteristics and exposures in cases as compared with controls. These studies are subject to several types of bias including selection and recall bias (Table 1.2). Matching treatment and control groups for known prognostic variables (e.g., age, gender, functional level) may partially control for confounding variables but rarely sufficiently negates them. One can also "overmatch" groups such that the groups are so closely matched that the exposure rates between cohorts are analogous [27]. In addition, the retrospective structure can lead to imprecise data collection and differential patient follow-up [28]. At the bottom of the evidence hierarchy are case reports and series and expert opinion. Case series are uncontrolled, unsystematic studies with a role mainly in hypothesis generation for future investigation and provide very little utility in guiding care. These reports are usually single-surgeon and single-center experiences which further impair generalizability.

Study Quality and the Hierarchy of Evidence

When placing a study into the surgical hierarchy, one must also consider study quality. In general, studies drop one level if they contain methodological problems (Table 1.1) [12, 29]. RCTs are only considered level I evidence when they have proper institution of safeguards against bias (Table 1.3), high precision (narrow confidence intervals), and high levels of patient follow-up; lesser-quality RCTs are assigned to level II evidence. Several instruments have been validated to assess the quality of RCTs which include the Cochrane risk of bias assessment tool (1–3), Jadad scale (range 0–5), Delphi list (range 0–9), and numeric rating scale (NRS; range 1–10). The Cochrane risk of bias assessment tool contains seven questions assessing six different bias domains that are rated as either a high, unclear, or low risk of bias within the trial [30]. These domains are selection bias, performance bias, detection bias, attrition bias, reporting bias, and other potential forms of bias. The seven questions within the tool provide a means for determining the risk of bias within the study (Table 1.4). The Jadad scale is another instrument to assess methodological quality of clinical trials, which contains three main areas of assessment: randomization, blinding, and loss to follow-up [31]. In addition, quality scoring systems exist for observational studies (i.e., cohort and case–control) such as the Newcastle–Ottawa scale for cohort studies [32]. For cohort studies, this tool assesses the rigor of cohort selection and comparability, ascertainment of exposure, outcome assessment (e.g., blinded assessment), and follow-up. From this, we have summarized crucial methodological elements of quality studies in Table 1.3. Although the actual validated instruments need not be used rigorously in everyday orthopedics, these quality criteria should be of

Table 1.3 Some essential methodological components of high-quality studies

Item	Study design	Description
A priori defined study protocol	RCT and observational	A protocol is critical to establish a priori primary and secondary outcomes which will require specific considerations, resources, and sample size. A priori outcomes maximize the benefits of cohort assignment (e.g., randomization) and limit overanalyzing trial data that leads to a higher rate of identifying significant differences by chance alone
Prospective	RCT and observational	Studies started before the first patient enrolled to improve cohort assignments, blinding, precision of data collection, completeness of follow-up, and study directness
Power analysis	RCT or observational	Determination of the appropriate sample size to detect a prespecified difference of clinical significance between cohorts. Based on standard deviation measurements from previous reputable studies. Ensures that a study has sufficient power to detect a clinically significant difference
Exclusion and inclusion criteria	RCT and observational	Defining the study population of interest and limiting patient factors which may confound outcomes greatly improve the generalizability of study results
Clinically relevant and validated outcome measures	RCT and observational	The efficacy of an intervention should be based on outcomes that are important to patients using instruments validated in capturing this clinical information
Blinding	RCT and observational	Surgeon blinding may not be possible, but blinding patients, outcome assessors, data analysts, authors of the results section, and outcomes' adjudicators is imperative to protect against detection and performance biases
Randomization	RCT	Safeguard against selection bias by ensuring equal distribution of prognostic characteristics between cohorts
Concealment	RCT	Investigators must be blinded to treatment allocation of patients to protect against undue influence on treatment allocation (i.e., selection bias)
Complete follow-up	RCT and observational	Complete follow-up of all patients should always be sought [74]. Appreciable risk of attrition bias exists when follow-up is less than 80% [76]
Expert-based design	RCT	A surgeon with expertise in one of the procedures being evaluated in a trial is paired with a surgeon with expertise in the other procedure. Subjects are then randomized to a surgeon, who performs only one of the interventions (i.e., the procedure that he/she has expertise and/or a belief that it is the superior procedure) [50]. A safeguard for expertise bias

Table 1.4 Cochrane risk of bias assessment tool

Bias domain	Source of bias	Support for judgment	Review authors' judgment (assess as low, unclear, or high risk of bias)
Selection bias	Random sequence generation	Describe the method used to generate the allocation sequence in sufficient detail to allow an assessment of whether it should produce comparable groups	Selection bias (biased allocation to interventions) due to inadequate generation of a randomized sequence
	Allocation concealment	Describe the method used to conceal the allocation sequence in sufficient detail to determine whether intervention allocations could have been foreseen before or during enrollment	Selection bias (biased allocation to interventions) due to inadequate concealment of allocations before assignment
Performance bias	Blinding of participants and personnel[a]	Describe all measures used, if any, to blind trial participants and researchers from knowledge of which intervention a participant received. Provide any information relating to whether the intended blinding was effective	Performance bias due to knowledge of the allocated interventions by participants and personnel during the study
Detection bias	Blinding of outcome assessment[a]	Describe all measures used, if any, to blind outcome assessment from knowledge of which intervention a participant received. Provide any information relating to whether the intended blinding was effective	Detection bias due to knowledge of the allocated interventions by outcome assessment
Attrition bias	Incomplete outcome data[a]	Describe the completeness of outcome data for each main outcome, including attrition and exclusions from the analysis. State whether attrition and exclusions were reported, the numbers in each intervention group (compared with total randomized participants), reasons for attrition or exclusions, and any reinclusions in analyses for the review	Attrition bias due to amount, nature, or handling of incomplete outcome data
Reporting bias	Selective reporting	State how selective outcome reporting was examined and what was found	Reporting bias due to selective outcome reporting
Other bias	Anything else, ideally prespecified	State any important concerns about bias not covered in other domains in the tool	Bias due to problems not covered elsewhere

Adapted from Ref. [30] with permission of BMJ Publishing Group LTD from Higgins Julian et al. Assessing risk of bias in included studies. In: Higgins JPT, Green S, eds. Cochrane handbook for systematic reviews of interventions. Wiley: 2008:187–241

[a]Assessments should be made for each main outcome or class of outcomes

central concern to the orthopedic surgeon in assessing the validity of results of published studies.

Additionally, the Consolidated Standards of Reporting Trials (CONSORT) Group published updated guidelines on how to report RCTs [33]. A previous systematic review of the surgical literature has reported poor compliance of surgical RCTs with its recommendations and endorsed educational initiatives to improve RCT reporting [34]. Although a thorough review of this document is beyond the scope of this chapter, it suffices to say that it serves as an excellent overview to aid in planning, executing, and reporting RCTs.

Randomized Surgical Trials: An Overview of Specific Methodologies

RCTs are considered the optimal study design to assess the efficacy of surgical interventions [29]. RCTs in the orthopedic literature have been described as explanatory (also called mechanistic) or pragmatic [35]. The explanatory trial is a rigorous study design that involves patients who are most likely to benefit from the intervention and asks the question of whether the intervention works in this patient population who receive treatment. Pragmatic trials include a more heterogeneous population, usually involve a less rigorous protocol and question whether the intervention works to whom it was offered [36]. The explanatory trial measures the efficacy of the intervention under ideal conditions, whereas the pragmatic trial measures the effectiveness of the intervention in circumstances resembling daily surgical practice. For that reason pragmatic trials have been said to be more generalizable, but this comes at the cost of reduced study power due to patient heterogeneity, as well as the potential for poor patient compliance with applicable treatments, which results in a larger range of treatment effects (increased noise). Explanatory and pragmatic approaches should be thought of as a continuum, and any particular trial may have aspects of each. The optimal trial design depends on the research question, the complexity of the intervention, and the anticipated benefit of the new intervention to the patient. Randomized trials are best suited to assess interventions with small-to-medium treatment effects. The smaller the anticipated effect, the more an investigator should consider optimizing the participant pool and intervention to provide clean results (explanatory trial) [36, 37].

Orthopedic surgery trials pose many methodological challenges to researchers. These include difficulties with recruitment of an adequate number of patients, blinding, differential cointervention, and outcome assessment. These difficulties are reflected in the quality of the current orthopedic literature. A previous review of orthopedic RCTs showed that a high percentage failed to report concealment of allocation, blinding, and reasons for excluding patients [38–40]. The results of these RCTs may be misleading to readers, and there is a growing consensus that larger trials are required [41]. A recent RCT has shown that many of these problems can be circumvented with multicenter surgical RCTs that include strict guidelines for cointervention and contain a blinded adjudication committee to determine outcomes [42].

The orthopedic community generally agrees that RCTs are the future of orthopedic research, but there have been many arguments against them. These include ethical assertions about patient harm which include (1) surgeons performing different operations at random where they may be forced to perform a procedure at which they are less skilled and comfortable performing, (2) conducting RCTs which involve withholding care such as in a placebo-controlled trial, and (3) inability to blind surgeons and the difficulty in blinding patients unless a sham RCT is conducted [25]. Although sham RCTs that facilitate patient blinding have been published, many ethics committees continue to deny its use on the basis of potential harm to patients who receive sham treatment [43, 44]. To help answer the question of surgical RCTs containing a placebo arm, a systematic review has highlighted the main obstacles and considerations with conducting a sham surgical trial [45]. This review describes the key feasibility issue with a placebo surgical trial is a slow recruitment rate due to a lack of eligible patients; however, sham surgical trials remain feasible, especially for procedures that are minimally invasive [45].

Others believe that discrepancies between RCTs and types of studies are overexaggerated. Concato and coworkers searched MEDLINE for meta-analyses of randomized controlled trials and meta-analyses of cohort or case–control studies in five clinical areas. They found “remarkable” similarities and concluded that these observational studies did not systematically overestimate the magnitude of the treatment effects. They ended with the statement that “the popular belief that only randomized, controlled trials produce trustworthy results and that all observational studies are misleading does a disservice to patient care, clinical investigation, and the education of health care professionals” [46]. Benson and colleagues looked at 136 reports on 19 diverse treatments. In most cases the estimates of treatment effects from observational studies and randomized controlled trials were similar. In only 2/19 treatment effects did the combined effect in the observational studies lie outside the 95% confidence interval for the combined magnitude in the RCTs [47]. Ioannidis and colleagues found that 25/45 (56%) topics in non-randomized studies showed larger treatment effect. 14/45 (31%) RCTs showed larger treatment effect, and in 7/45 (16%), the magnitude of the differences would not be expected by chance alone [48]. MacLehose and coworkers systematically reviewing the comparisons of effect size from randomized and non-randomized studies found that effect size discrepancies between RCTs and observational studies were lower in high-quality studies. These studies lend to the argument that the quality of the study might be more important than the research design [49].

The Expertise-Based Design

In surgical trials, an ethical dilemma can arise if the surgeon believes one intervention is superior or has more expertise with one procedure but is forced to perform the other procedure due to random patient allocation. In such a circumstance, it is unethical for the surgeon to be involved in the trial. To address this problem, Dr. P.J. Devereaux has published extensively on the expertise-based design where the patient is randomized to one of the two groups of surgeons and not to the procedure itself [50]. This is in contrast to the parallel RCT where surgeons perform both procedures in random order. This avoids the aforementioned ethical dilemma and also minimizes performance bias where the results of the trial may be heavily impacted by surgeon experience or comfort. The downside of expertise-based design is that in some research areas, such as trauma surgery, both surgeon groups need to be available at all times to perform their designated intervention. This may limit feasibility in small centers with scarce resources.

Parallel Trial Design

The most commonly utilized and simplest design is the parallel randomized trial. Participants are assigned to one of two or more treatment groups in a random order. The most basic of these involves two treatment groups – a treatment and control arm. Trials can have more than two arms to facilitate multiple comparisons, but this requires larger sample sizes and increases the complexity of analysis.

Factorial Design

The factorial trial enables two or more interventions to be evaluated both individually and in combination with one another. This trial design is thought to be economical in some settings because more than one hypothesis (and treatment) can be tested within a single study. For example, Petrisor and colleagues [51, 52] conducted a multicenter, blinded randomized 2 × 3 factorial trial looking at the effect of irrigation solution (castile soap or normal saline) and pressure (high versus low versus very low pressure lavage) on outcomes in open fracture wounds. The corresponding 2 × 3 table is shown in Table 1.5. From this table the investigator wound compare the 1140 patients receiving soap with the 1140 who received saline solution. Concurrently, comparison can be made between each of the pressure categories with 760 participants.

With factorial designs there may be interaction between the interventions. That is, when treatments share a similar mechanism of action, the effect of one treatment may be influenced by the presence of the other. If the treatments are commonly co-administered in surgical practice (such

Table 1.5 A 2 × 3 factorial trial table from the fluid lavage in open fracture wounds (FLOW) randomized trial

	Gravity flow pressure	Low pressure	High pressure	Total
Soap solution	380	380	380	1140
Saline	380	380	380	1140
Total	760	760	760	2280

Source: Ref. [77]: Flow Investigators. Open Access Article

This study had a target sample size of 2280 participants and was designed to assess the impact of irrigation solution (soap or saline = 2 categories) and lavage pressure (gravity flow, low, and high pressure = 3 categories) in open fracture wounds as the aforementioned lavage study), then this trial design is ideal, as it allows for assessment of the interaction to identify the optimal treatment combination. Treatment interactions may be negative (antagonistic) or positive (synergistic), which reduce or increase the study power, respectively. This consequently affects sample size, and therefore potential interactions should be considered in the design phase of the study.

Other Randomized Designs

In surgical trials the unit of randomization is often the patient or the limb of interest [15, 51]. In other words, when we randomize to one treatment versus another, we are usually talking about randomizing patients. In some circumstances, however, randomizing patients may not be feasible or warranted. When the intervention is at an institutional or departmental level, such as with implementation of a new process, guideline, or screening program, patient randomization is difficult and often impossible. This is for several reasons: (1) surgeons or health-care practitioners are unlikely to use a new guideline for one patient and not the other; (2) patients randomized to different interventions will often educate each other (a process called contamination); and (3) department-wide programs are often expensive and challenging to implement, so running multiple programs is not practical or economical. In these circumstances, it is best to randomize institutions, departments, or geographical areas. This process is called cluster randomization. For instance, if one were to implement a chewing tobacco cessation program among major league baseball players, it would make more sense to randomize teams to the cessation program rather than individual players. Two important aspects of cluster trials are as follows: (1) participants within clusters are more similar with regard to prognostic factors than between clusters, and (2) a sufficient number of clusters must be available to provide prognostic balance and sufficient power. In general, because patients within clusters are similar, there is a reduced power and an increased required sample size of cluster trials. In the analysis, one can compare the outcomes of entire clusters or individuals. Individual patient analysis requires an estimate of patient similarity (called an intraclass correlation coefficient). The more similar the participants are within clusters, the higher the intraclass correlation coefficient, and the required sample size is consequently greater to reach significance.

Another trial design is the crossover trial where patients are randomized to a treatment and then receive the other treatment after a designated period of time. Each participant serves as their own control when a within-patient analysis is conducted. These studies have significant power but are rarely conducted in orthopedic surgery because they require chronic diseases with treatments that are quickly reversible once stopped. For example, Pagani and colleagues [53] conducted a crossover trial assessing the gait correction of 4-valgus and neutral knee bracing in patients with knee OA. All patients performed gait and stair climbing assessments without an orthosis and then were randomized to one of the two bracing arms for 2 weeks followed by crossover to the other bracing arm for 2 weeks. Because of the power of this analysis, they demonstrated a statistically significant improvement in gait mechanics with 4-valgus bracing with only 11 patients.

Special Considerations Within the Hierarchy

In addition to reviews of level II studies [54], reviews of high-quality RCTs with inconsistent results [55] are also regarded as level II evidence (Table 1.1). For instance, Hopley and associates performed a meta-analysis comparing total hip arthroplasty (THA) to hemiarthroplasty (unipolar and bipolar) which included seven RCTs, three quasi-randomized, and eight retrospective cohort studies. This review reported reduced reoperation rates and better functional improvements after THA than hemiarthroplasty. However, from review of this study's forest plot of randomized studies, one can see that there is a wide range in point estimates leading to imprecision within their pooled effect size (Fig. 1.2). This analysis encountered methodological issues such as lack of concealment, heterogeneity of study inclusion criteria, and type of hemiarthroplasty; all of these factors would negatively affect this meta-analysis's rating within the hierarchy. In addition, the included review of retrospective cohort studies would be regarded as level III evidence (Fig. 1.2; Table 1.1).

Grades of Recommendation: From the Bench to the Operating Room

The quality of best available evidence and the magnitude of treatment effect reported play a central role in the strength of clinical practice

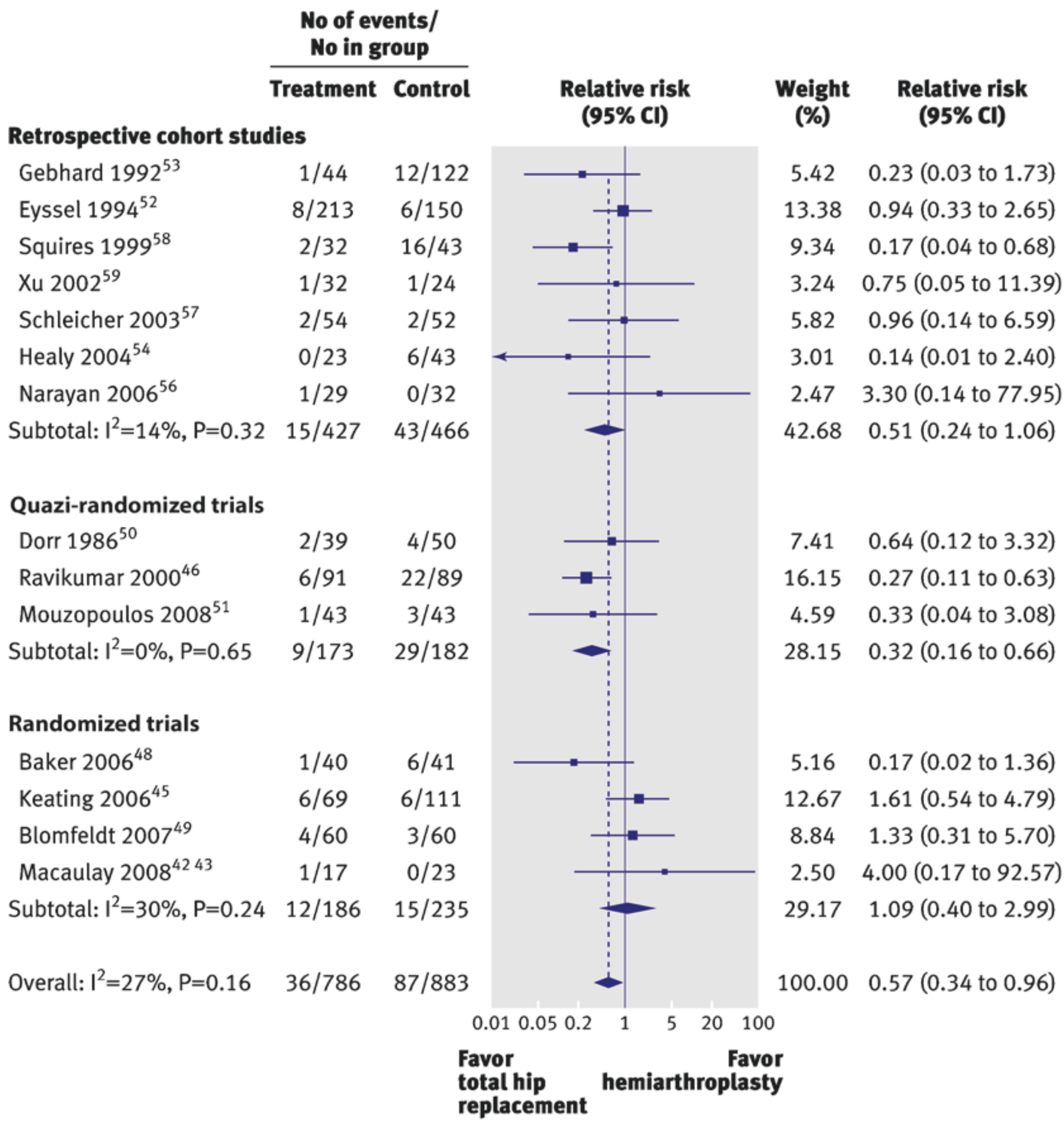

Fig. 1.2 Sample forest plot that shows the point estimates and 95% confidence intervals of individual primary studies and pooled effect sizes represented as a relative risk (*diamond*). This meta-analysis provided separate pooled effect sizes for each type of study design and an overall pooled estimate shown at the *bottom*. Estimates to the *left* favor total hip arthroplasty and to the *right* hemiarthroplasty (References and reference numbers in figure refer to reference list in source article.) (Used from Ref. [55]: with permission of BMJ Publishing Group LTD from Hopley et al.)

Table 1.6 Modified GRADE quality assessment criteria [56]

Quality of evidence	Study design	Lower if[a]	Higher if[a]
High	Randomized trial	*Study quality*: –1 Serious limitations –2 Very serious limitations –1 Important inconsistency *Directness*: –1 Some uncertainty –2 Major uncertainty –1 Sparse data –1 High probability of *Reporting bias*	*Strong association*: +1 Strong, no plausible confounders, consistent and direct evidence[b] +2 Very strong, no major threats to validity and direct evidence[c] +1 Evidence of a dose–response gradient +1 All plausible confounders would have reduced the effect
Moderate	Quasi-randomized trial		
Low	Observational study		
Very low	Any other evidence		

Source: Ref. [57]: Atkins et al. Open Access Publication

[a]1 = move up or down one grade (e.g., from high to moderate). 2 = move up or down two grades (e.g., from high to low). The highest possible score is high (4) and the lowest possible score is very low (1). Thus, for example, randomized trials with a strong association would not move up a grade

[b]A relative risk of >2 (<0.5), based on consistent evidence from two or more observational studies, with no plausible confounders

[c]Available studies provide direct comparisons between alternative treatments in similar participant populations

recommendations. A recommendation for or against an intervention is based on a comprehensive systematic review of available evidence, evaluation of the methodological quality of available studies, and focus group discussion of subspecialty experts to achieve consensus. In 2004, the Grading of Recommendation Assessment, Development, and Evaluation (GRADE) Working Group developed a system for scoring the quality of evidence (Table 1.6) [57]. This scoring system places more weight on studies with better design, higher methodological quality, and larger treatment effects, but also considers factors such as directness [57]. The GRADE criteria are applied to all critical outcomes. Once the evidence is "graded" and several factors such as calculation of baseline risk in the target population, feasibility of the proposed intervention, and a benefit versus harm assessment are completed, a recommendation level is assigned which includes one of the following: (1) do it, (2) probably do it, (3) toss up, (4) probably do not do it, and (5) do not do it [36, 37]. These recommendations guide surgeons by suggesting that most (items 1 and 4) or many (items 2 and 4) well-informed surgeons would make a particular decision, based on systematic review of the literature. The GRADE approach provides a basic foundation for translating evidence into practice and serves as a useful communication tool for clinicians and review panels. However, even valued input and consensus from expert panels do not replace a sound understanding of the available evidence (e.g., from a critical appraisal of a meta-analyses) and good clinical judgment. Hence, we return to the essence of EBO which considers best available evidence, clinical judgment, patient values, and clinical circumstances when making treatment decisions (Fig. 1.1).

Evidence-Based Orthopedics: Advances and Misconceptions

EBM has been recognized as one of the top 15 medical discoveries of the last 160 years. In the past decade, it revolutionized clinical research and care by providing the basis for the development of clinical trials, systematic review, and validated outcomes. International standards have been developed such as the Oxford Centre for Evidence-Based Medicine, the Cochrane Collaboration, and Britain's Center for Review, which are providing updated systematic reviews of the effects of medical and surgical care [58]. In orthopedics, JBJS has fully incorporated the hierarchy of evidence into all published manuscripts, and this has been utilized in annual meetings of the American Academy of Orthopedic Surgeons (AAOS) [59]. As a consequence, the overall quality of clinical trials and systematic reviews in orthopedics appears to be improving [23, 60].

Improving the validity of orthopedic studies is only one facet of EBO in its pursuit to improving standards in orthopedic practice. EBO also requires a willingness of an orthopedic society, for example, the AAOS in this case, to incorporate best evidence into practice [61]. Traditionally, there has been a resistance to perform well-designed studies in orthopedics and misconceptions about the practice of EBO [62, 63]. In contrast, an international cross-sectional survey among International Hip Fracture Research Collaborative (IHFRC) surgeons revealed that most surgeons are willing to change their practice based on large-scale clinical trial results [64]. Thus, it appears that orthopedists are recognizing the need for higher standards to ensure best care for patients with musculoskeletal conditions.

Despite the global movement of EBO, misconceptions about it exist. There have been criticisms that EBO only gives information about the average patient and that simple application of trial results is analogous to "cookbook" medicine [16, 65]. The approach of EBO is actually exactly the opposite. EBO utilizes a bottom-up approach which begins with a surgical problem and incorporates best available evidence, surgical expertise and experience, the clinical context, and patient preferences. Surgical expertise and a working understanding of EBO are essential to appreciate if the available evidence applies well to the individual patient and clinical circumstances, and if so, how it should be applied. For example, if one were to encounter the 65-year-old marathon runner with a displaced femoral neck fracture after a fall, one must consider the available evidence of improved outcomes of THA as compared to hemiarthroplasty and internal fixation, the current limitations of this literature, the patient's functional status and physiologic age, and patient preferences and expectations with regard to the complication profile and functional outcomes of these procedures [55, 66, 67].

Some have equated EBO with only RCTs and meta-analysis, as these are considered the highest quality of evidence. On the contrary, EBO proposes to use the most appropriate study design and methodology to answer the surgical question with maximal validity. RCTs are more effective when the condition is common rather than when it is rare. For instance, many conditions in orthopedic oncology are too scarce to permit an RCT, but EBO advocates that studies in this field institute as many safeguards as possible to limit bias, to focus on outcomes that are important to patients, and to perform systematic review when possible [68]. In addition, evaluation of diagnostic efficacy is best answered by cross-sectional studies rather than RCTs. Questions regarding biomechanics and prosthetic wear properties are often best addressed by studies in basic science. Despite this, randomized trials have claimed much of the focus of EBO because of their important role in providing valid outcomes for surgical interventions (Table 1.1). Observational studies that are designed well have their place. A well-designed observational study can limit bias and confounding that is associated with nonrandomization. Some questions answered by this type of study can be the etiology, natural history, identification of prognostic factors, and the possibility of adverse treatments. From an ethical standpoint, it would be unethical to randomize treatment groups to management that may be harmful [69].

Thus, it is important to keep in mind that many factors determine the ideal study design that best answers the clinical problem. Such considerations include the type of question being asked (e.g., therapeutic efficacy, diagnosis), frequency of the condition, ethics of intervention, the quality and uncertainties of available evidence, and surgical equipoise.

Closing Comments

Ultimately, becoming an evidence-based orthopedic surgeon is not a simple task. One must understand the hierarchy of evidence, from meta-analysis of RCTs to clinical experience. In making surgical decisions, a surgeon should know the strength of best available evidence and the corresponding degree of uncertainty. The process of exploration of evidence to answer specific questions is equally critical. The ability to search the available literature, evaluate the methodological quality of studies to identify best evidence, determine the applicability of this information to the patient, and appropriately store this information for further reference requires education and practice. For educational modules on these topics, we direct you toward several additional resources to this text including *Clinical Research for Surgeons* [25], the *Users' Guides to the Medical Literature: A Manual for Evidence-Based Clinical Practice* [2], the JBJS *Users' Guide to the Surgical Literature: How to Use a Systematic Literature Review and Meta-Analysis* [70], and the *Journal of Orthopedic Trauma* evidence-based orthopedic trauma summaries [8].

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Part II

Spine Trauma

2 Cervical Spine Clearance

Daniel G. Tobert and Mitchel B. Harris

GB: A 25-Year-Old Male with High-Energy Blunt Trauma

Case Presentation

GB is a 25-year-old male involved in an all-terrain vehicle (ATV) accident. Upon emergency medical services (EMS) arrival to the scene, the patient demonstrated a Glasgow Coma Scale (GCS) score of 12 and complained of chest pain. A cervical collar was placed in the field, and the patient was taken to a local emergency room. Primary survey revealed a flail chest and hemodynamic instability. In the trauma bay, the patient is intubated and stabilized hemodynamically. His CXR demonstrated multiple rib fractures and a hemothorax. A left-sided chest tube is placed. Secondary survey is otherwise unremarkable. Orthopedics is consulted for cervical spine clearance. The purpose of this chapter is to review the current evidence for cervical spine clearance.

Past medical history and past surgical history are unremarkable. The patient has no allergies, takes no medications, and has no toxic social habits.

D. G. Tobert (✉) · M. B. Harris
Department of Orthopaedic Surgery, Harvard Medical School, Massachusetts General Hospital, Boston, MA, USA
e-mail: dtobert@partners.org

On physical examination prior to intubation, the patient was grossly moving all four extremities spontaneously.

X-rays and CT scan images are demonstrated (Figs. 2.1a, b, 2.2a, b, and 2.3a, b).

Interpretation of Clinical Presentation

This case highlights the challenges of cervical spine clearance in patients with cognitive impairment. Of the 41 million visits each year to emergency rooms in the United States for traumatic injury, 80% of those are the result of blunt trauma mechanisms [1, 2]. Cervical spine injury, which includes fracture, dislocation, and purely discoligamentous and combined injury patterns, occurs in 1–3% of patients sustaining blunt trauma [3–5]. Although the majority of blunt trauma patients do not have a cervical spine injury, a systematic evaluation of the cervical spine in each blunt force trauma patient is required to avoid neurologic compromise. The goal of cervical spine clearance is to confirm the absence of clinically relevant injuries.

EMS personnel are instructed to presume cervical spine injury in all blunt trauma patients. However, the use of cervical orthoses in the pre-hospital setting has come under review recently. Some authors recommend foregoing collar

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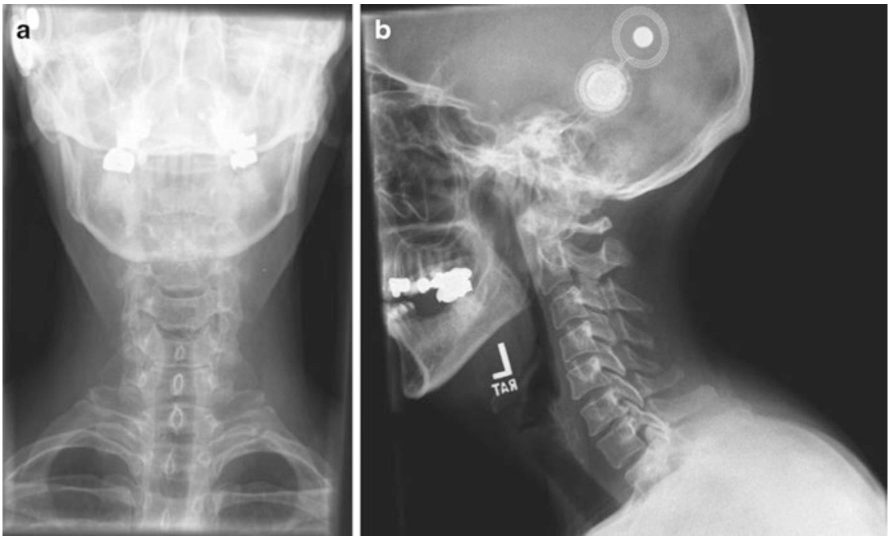

Fig. 2.1 (**a**) AP radiograph C-spine. (**b**) Lateral radiograph C-spine

Fig. 2.2 (**a**) Coronal CT spine. (**b**) Sagittal CT spine

immobilization completely except during extrication and instead utilizing a screening algorithm with high-risk patients secured via head blocks and straps [6]. Ultimately, it is the clinician's responsibility to confirm proper cervical spine immobilization is in place upon arrival to the emergency department (ED) [7]. ATLS protocol was developed to systematically identify significant pathology and allow rapid institution of life-saving intervention due to a flail chest and hemodynamic instability [8].

During the secondary survey, the patient is rolled to the side to allow inspection and palpation of the dorsal spine anatomy. The presence of ecchymosis, crepitus, step-off, or gaps between the spinous processes should be noted. The roll maneuver provides an opportunity for the clinician to perform a rectal exam to assess the tone of the external anal sphincter and perianal sensation. The American Spinal Injury Association (ASIA) worksheet is a helpful guide for motor and sensory testing [9]. If the

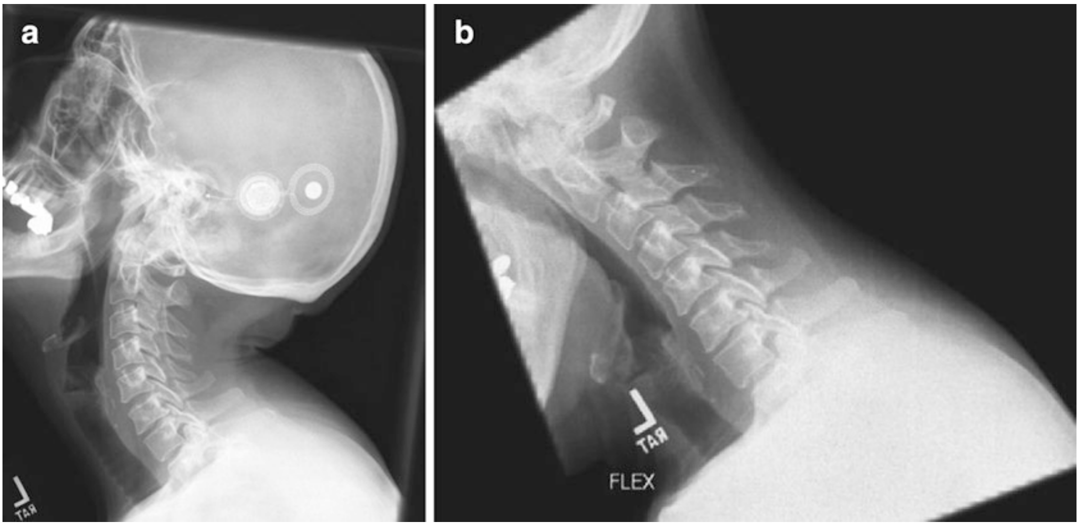

Fig. 2.3 (**a**) Extension radiograph C-spine. (**b**) Flexion radiograph C-spine

patient is responsive, the examiner should inquire about transient paresthesias or weakness at the time of injury, as this could indicate serious cervical spine injury. Patient GB was noted to be moving all four extremities in the ED, but persistent hemodynamic instability and respiratory concerns led to intubation, precluding completion of the secondary survey and obtaining a reliable physical examination. While the observation of extremity movement is important and should be documented in the medical record as such, it does not substitute for independent muscle group testing.

The physical exam should be interpreted in the context of the patient's mental status at the time of examination. The GCS score is an objective, neurologic metric that is reproducible and can be trended over time [10]. Delirium is frequently encountered in the trauma setting and may be secondary to the initial trauma, intoxication, or opioid analgesia. The Confusion Assessment Method (CAM) is a validated instrument for rapidly assessing delirium in the trauma setting [11]. Dementia is a disease predominantly affecting the elderly and therefore is a common comorbidity for the blunt force geriatric trauma population. While dementia does not automatically exclude a physical exam, the risk of delirium superimposed on patients with dementia is elevated in the trauma setting, and clinicians should be cognizant of this factor [12]. The Mini-Cog instrument is a validated measure that can screen stable trauma patients for dementia [13]. After the clinical exam is completed, or determined unreliable, the patient can be classified into one of four categories: (1) awake and alert, (2) short-term cognitive impairment, (3) symptomatic, or (4) long-term cognitive impairment. Patient GB was intubated in the ED for a flail chest and HD stable. A reliable, comprehensive exam was not obtained prior to intubation. The duration of intubation for flail chest can be highly variable; we will assume a reliable exam will not be obtained in the next 48–72 h and therefore classify him in the "long-term cognitive impairment" category.

Interpretation of Radiographic Images

The images obtained for patient GB include AP and lateral plain films, computed tomography (CT) of the cervical spine, and flexion/extension (F/E) plain films. On review of the static lateral film, there are no obvious fractures; the anterior vertebral, posterior vertebral, spinolaminar, and posterior spinous lines are all intact; and the atlanto-dens interval is not increased. On the static AP film, the lateral edges of lateral masses are aligned, and the spinous processes are evenly spaced. Plain film radiography was the traditional screening method for cervical spine injury in blunt force trauma. While inexpensive to obtain, plain film radiography has a sensitivity of 52–70% for detecting cervical spine injuries [14, 15].

The CT images provided for patient GB include a coronal and parasagittal reformation. In the coronal CT image, the disk spaces are preserved and relatively equal. The lateral masses of C1 do not overhang the ipsilateral lateral masses of C2. On the parasagittal C2 image, there is no listhesis and no overt evidence of a fracture. Careful attention at the C6/C7 segment reveals subtle lucencies through the anterior portion of the C7 vertebral body and through a posterior osteophyte complex at the C6/C7 intervertebral disk. Multi-detector CT (MD-CT) scanners offer vast improvement in spatial resolution in comparison to plain film radiography. Modern 64-slice MD-CT scanners typically provide 1-mm axial collimation with 1-mm reformations in the sagittal and coronal plane. Although more expensive than plain films, cost-effectiveness studies show that the increased cost upfront for MD-CT is offset by the decrease in missed injuries [16, 17]. The Eastern Association of Surgery and Trauma (EAST) recommended MD-CT as the primary imaging modality for cervical spine injury in 2009 based on the improved resolution of MD-CT and relatively low sensitivity and specificity of plain film for detecting cervical spine injury [18].

The F/E films obtained for patient GB do not show evidence of instability. However, the role of F/E films in the acute trauma setting is limited. Often, these films do not span the occipitocervical junction to the cervicothoracic junction, and the dynamic motion is less than 30° from neutral [19, 20]. Furthermore, protective muscle spasm in the acute setting can mask pathologic motion. All of these factors argue against the utility of F/E as a screening modality for ligamentous injury in the acute setting. Therefore, the authors recommend against F/E views in the acute evaluation for cervical spine injury.

Declaration of Specific Diagnosis

Patient GB is a 25-year-old man who sustained high-energy blunt force trauma, immobilized with a rigid cervical orthosis, intubated for respiratory distress and hemodynamic instability secondary to a flail chest with hemothorax. He is being evaluated for cervical spine clearance in the setting of long-term cognitive impairment due to an anticipated prolonged intubation.

Brainstorming: What Are the Treatment Goals and Options?

Objectives during the evaluation for cervical spine clearance:

1. Presumption of injury until proven otherwise.
2. Immobilization with a hard cervical orthosis until the absence of a clinically relevant injury (necessitating prolonged immobilization or surgery) is determined.
3. Early detection and intervention for cervical spine injury.
4. Accurately confirm the absence of a clinically relevant cervical spine injury.

Diagnostic Options:

1. Clearance without imaging for patients that are awake, alert, and asymptomatic
2. Multi-detector computed tomography (MD-CT)
3. Subacute dynamic plain films for patients with negative MD-CT imaging and persistent midline tenderness
4. Magnetic resonance imaging (MRI)

Evaluation of the Literature

Relevant literature was queried in PubMed with the following keywords: “cervical spine,” “clearance,” and “blunt trauma.” This search yielded 100 articles, which were reviewed. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

All patients who sustain blunt trauma warrant cervical spine clearance. During the acute evaluation, a patient is categorized into one of four clearance categories: (1) alert and asymptomatic, (2) short-term cognitive impairment, (3) symptomatic, and (4) long-term cognitive impairment [21]. The purpose of this review section is to highlight the evidence that led to the algorithms for each category.

Alert and Asymptomatic

There is level 1 evidence supporting the notion that alert and asymptomatic patients who sustain blunt force trauma do not need imaging for clearance. The Canadian C-Spine Rule (CCR) was a prospective, multicenter trial published in 2001 that enrolled 8924 adult blunt trauma patients with a GCS of 15 and stable vital signs. Using the data from these patients, the authors derived a decision rule yielding 100% sensitivity for clinically relevant cervical spine injury [22]. The decision rule seeks to find the absence of high-risk factors and the presence of low-risk factors followed by the ability to axially rotate the neck to prevent unwarranted screening in radiographic studies.

The National Emergency X-Radiography Utilization Study (NEXUS) criteria were validated in a prospective, multicenter trial that screened 34,069 patients [23]. If all five criteria (alert, not intoxicated, no distracting injury, no focal neurologic deficit, and no posterior midline tenderness) are present, the negative predictive value for relevant cervical spine injury is 99.6%. Stiell and colleagues performed a prospective comparison of the CCR and NEXUS criteria on 7438 patients and reported a 99.7% sensitivity for detection of relevant cervical spine injury by CCR compared to 90.7% sensitivity for the NEXUS criteria, which was a substantial decrease from the original NEXUS validation study [24]. Despite the CCR superiority demonstrated in the comparison trial, there was greater misinterpretation of the CCR algorithm by clinicians, likely due to its complexity.

Patients who are over the age of 65 deserve a careful mental status evaluation after sustaining blunt force trauma. The incidence of cervical spine injury after blunt force trauma is doubled in the elderly population, and a 2014 study showed elderly patients can have cervical spine injury despite passing NEXUS criteria [25]. It is the authors' opinion that all patients over 65 years of age be screened for delirium and dementia with objective mental status instruments such as the CAM and Mini-Cog to determine if a patient is truly "alert."

Anderson and colleagues performed a meta-analysis on 14 level I and level II studies, which aggregated 61,489 patients [26]. Using the protocols included in each study (CCR, NEXUS, or individual institutional protocols), the meta-analysis reported a 99.8% negative predictive value and 98.1% sensitivity for relevant cervical spine injury after blunt trauma. There is high-quality evidence that the cervical spine can be cleared in alert and asymptomatic patients without imaging.

Short-Term Cognitive Impairment

Patients are classified here if they are not assessable due to a cognitive impairment expected to last less than 48 h. The etiologies of cognitive impairment in this category are treatable and commonly include intoxication, delirium, and distracting injury. A GCS score of 15 denotes spontaneous eye opening, command following, and orientation to person, place, year, season, and month [10]. Inability to meet these benchmarks should alert the clinician to a potential cognitive impairment.

The definition of a distracting injury has not been formally delineated in the literature. During the validation of the NEXUS criteria, the identification of a distracting injury was left to the clinician's individual assessment [23]. The subjective nature of pain precludes a comprehensive list of injuries significant enough to be distracting. Heffernan and colleagues studied 40 patients with cervical spine injuries and reported that of the 7 patients that did not have midline tenderness, all had concomitant injuries above the abdomen [27]. Another study looked at 88 cervical spine injuries and found the 4 patients without midline cervical tenderness all had anterior chest injuries [28]. A study with adequate statistical power to determine the role of a distracting injury in cervical spine clearance was not found in the literature.

It is the authors' opinion that if a patient is unable to comply with clinical examination secondary to the pain of a concomitant injury or due to intoxication, immobilization should continue until satisfactory analgesia is obtained. Cervical spine clearance without imaging can proceed once a patient regains a normal cognitive state, and a reliable examination reveals the patient is asymptomatic. If symptomatic at the time of exam, or persistent impairment prevents a reliable exam, the patient should be reclassified into a different category.

Symptomatic

Patients with acute neurologic symptoms (either persistent or transient) or midline cervical tenderness require radiographic screening for cervical spine injury with MD-CT [18]. Detection of an injury via MD-CT mandates a spine service consultation for treatment recommendations and determination if additional imaging is needed. MRI provides excellent resolution to evaluate acute injury to the spinal cord and discoligamentous structures without exposure to ionizing radiation. However, the role of MRI is adjunctive and should not be used as a primary screening modality due to the current expense and lengthy acquisition time.

If an injury is not detected by MD-CT, the patient should be reexamined for persistent midline tenderness or acute neurologic deficits. A persistent acute deficit should be further investigated with an MRI to ascertain an occult unstable ligamentous injury, spinal cord trauma, or epidural hematoma. The optimal treatment for a patient who is alert and neurologically intact with negative MD-CT imaging but continued midline tenderness has yet to be determined. One option is continued immobilization in a cervical orthosis and repeat examination in 10–14 days. Flexion/extension radiographs can be obtained at the time of reexamination if the patient is able to perform them. However, Sierink and colleagues argue that F/E views are largely unhelpful if more detailed imaging (CT or MRI) has been obtained [29].

While continued immobilization for those with persistent midline tenderness is a cost-effective strategy, it is not without risk. Moran and colleagues found that elderly patients are at increased risk of dysphagia, lower respiratory tract infections, delirium, falls, and hospital readmission with prolonged immobilization [30]. Additionally, a prospective observational study of 178 patients with negative MD-CT and persistent midline tenderness who received a subsequent MRI found 22% of the cohort with clinically significant cervical spine injuries (defined by a recommendation for continued collar immobilization or surgery) [31]. However, more recently Resnick and associates prospectively evaluated 830 patients with persistent midline tenderness or focal neurologic deficit and concluded MD-CT alone was adequate to identify clinically relevant injuries [32].

In conclusion for symptomatic patients, strong evidence supports MD-CT as the initial imaging modality. Patients with a negative MD-CT but acute neurologic deficits should undergo further investigation with MRI. Given the discordance in the literature regarding patients with persistent midline tenderness and negative MD-CT, it is the authors' opinion that cervical immobilization should be continued for 10–14 days and reexamined at that time. If a patient is at high risk for complications from continued immobilization, MRI can be used to clear the cervical spine.

Long-Term Cognitive Impairment

Patients with cognitive impairment anticipated to last longer than 48–72 h represent the most controversial category. Cervical spine clearance in the obtunded blunt force trauma patient remains a heavily researched topic. The debate centers on whether a negative MD-CT is sufficient to clear the cervical spine in an obtunded patient or whether an adjunctive MRI is needed. Contributing to the controversy is a lack of consensus on the definition of "obtunded" and "clinically relevant injury." Multiple studies exist in the literature for both sides, but most are retrospective single-institution studies owing to the difficulty of randomized controlled trials and low probability of receiving ethical committee clearance to devise a sufficient trial addressing the subject.

Evidence supporting MRI in addition to MD-CT references the rare but devastating sequelae of a missed unstable injury [33]. James and associates performed a systematic review of 11 studies and found that 11 of 1535 obtunded patients with negative MD-CT had an unstable cervical spine injury on MRI requiring operative treatment [34]. A pooled meta-analysis of 1550 obtunded patients by Schoenfeld and associates reported the addition of an MRI scan led to immobilization in 5% and surgical treatment in 1% of the cohort [35]. Conversely, Panczykowski and coworkers performed a meta-analysis of 17 studies in over 14,000 obtunded trauma patients. Of 12,754 patients with negative MD-CT, there were 3 patients with missed unstable injuries. The authors argue for cervical collar removal after a negative MD-CT using a Bayesian nomogram, which depicts the posttest probability for relevant injury after a negative MD-CT approach zero [36]. EAST recently published conditional recommendations in a practice management guideline for collar removal in obtunded patients after negative high-quality MD-CT based on a systematic review of 12 studies [37]. While acknowledging documented reports of neurologic deterioration after a negative MD-CT and cervical collar removal, the EAST guideline presents a persuasive argument for abandoning the two-stage (CT and MRI) imaging protocol for obtunded patients. The guidelines point out that the negative predictive value of negative MD-CT approaches 100% and the false-positive rate of MRI is not insubstantial. A false-positive most often occurs when peri-ligamentous edema leads to an equivocal determination of structural competency and results in treatment inconsistencies with respect to immobilization.

Considering the treatment recommendations for the obtunded trauma patient is wholly dependent on imaging results, there is benefit when more than one trained clinician reviews the images. Simon and coworkers showed a 24% discrepancy rate between spine surgeons and radiologists when reviewing MD-CT imaging for trauma patients [38]. Another study reported that review of cervical spine MD-CT in trauma patients by a second radiologist reveals missed injury in 5% and a false-positive injury in 3% of patients [39].

Based on the data currently available, it is the authors' opinion that all trauma patients with long-term cognitive impairment undergo MD-CT and have the images reviewed by at least two clinicians trained to detect cervical spine injuries. If both clinicians independently agree on the absence of injury, the cervical spine can be cleared on imaging alone. If the opinions differ or are equivocal for an unstable injury, MRI should be obtained.

Literature Inconsistencies

The algorithms for cervical spine clearance in the alert and asymptomatic, short-term cognitive impairment and symptomatic categories are based on sufficient evidence in the literature. Despite the abundance of literature for blunt force trauma patients with long-term cognitive impairment, there is a high degree of discordance. Given the low likelihood of obtaining approval from institutional review boards for a randomized trial of patients in this category, other study designs should be used. The statistical methodologies of propensity matching could yield high-quality data that would help our understanding of how to treat patients in this category.

Evidentiary Table and Selection of Treatment Plan

Table 2.1 summarizes the applicable data. In the case vignette, patient GB sustained high-energy blunt force trauma and is currently intubated and sedated for a flail chest and hemodynamic instability with anticipated long-term cognitive

Table 2.1 Evidentiary table: A summary of the quality of evidence for approach to cervical spine clearance

Author (year)	Description	Summary of results	Level of evidence
Hoffman et al. (2000) [23]	Prospective, multicenter cohort study	Validation of NEXUS criteria applied to 34,067 patients across 21 trauma centers. Reported sensitivity was 99.0% and negative predictive value of 99.8%	I
Stiell et al. (2001) [22]	Prospective, multicenter cohort study	Derivation study of 8924 patients that were awake and alert from 10 centers that led to the formulation of the Canadian C-Spine Rule.	I
Resnick et al. (2014) [32]	Prospective observational study	830 patients with persistent midline tenderness or focal neurologic deficit. Of the 681 with negative MD-CT, 15 patients had injury on MRI but did not change management	II
Schoenfeld et al. (2010) [35]	Meta-analysis study	Pooled analysis of 1550 obtunded trauma patients. The addition of MRI revealed missed injuries on 6% of the cohort. 5% required additional immobilization and 1% required surgery	III
Patel et al. (2015) [37]	Systematic review study	Comprehensive systematic review of 12 studies leading to the EAST recommendation that MD-CT alone can clear C-spine in obtunded patients	III

impairment [22, 23, 32, 35, 37]. The observation that he was moving all four extremities before intubation is helpful to note but does not represent a reliable, comprehensive clinical examination. The static plain films are negative for injury. Although dynamic plain films are presented here, there is not a role for F/E in the acute setting and should be reserved only for the subacute setting. The MD-CT images available include one coronal and one parasagittal image. On the parasagittal image, there is suggestion of injury to a posterior annulus osteophyte, but additional images are needed to determine if this is artifact or true injury. For patient GB, the authors recommend further evaluation of all MD-CT images by two clinicians trained to evaluate for cervical spine injuries. If there is continued concern for injury, further evaluation with MRI is warranted. If both clinicians conclude there is no evidence of injury after thorough MD-CT review, patient GB's cervical spine can be cleared on MD-CT imaging alone.

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3 Cervical Spine Fracture-Dislocation

Kevin R. O'Neill, Michelle S. Shen, Jesse E. Bible, and Clinton J. Devin

MJ: A 43-Year-Old Female with Neck Pain and Paralysis

Case Presentation

MJ is a 43-year-old female who presents to the emergency department after a fall from a standing height. On presentation, the patient complains of severe neck pain and bilateral upper and lower extremity weakness. Her primary survey demonstrates a clear airway and hemodynamic stability. She denies any LOC and maintains a GCS of 15. Her secondary survey is negative.

On physical examination, the patient is awake and alert. She demonstrates 5/5 strength in her deltoids, 5/5 strength of the biceps, 1/5 strength of the triceps, and 0/5 strength distally in the upper extremities. She has 2/5 gastroc strength and 1/5 quad strength. Sensation is intact at the C6 Level but is diminished below. She demonstrates intact biceps, patella, and Achilles reflexes but has an absent triceps reflex. She has diminished rectal tone and demonstrates an intact bulbocavernosus reflex and anal sensation.

Cervical spine CT and MRI C-spine images are included in Figs. 3.1a–e and 3.2a–c.

Interpretation of Clinical Presentation

Cervical spine trauma accounts for roughly half of the 11,000 spinal cord injuries that occur annually in North America. Injuries to the subaxial cervical spine, involving levels C3–C7, constitute two-thirds of cervical spine fractures and more than three-fourths of spine dislocations [1]. Despite this prevalence, the optimal medical and surgical treatments are not clear.

Patients with injury mechanisms that place them at risk of a spine injury should be immobilized at the scene with a cervical collar and rigid backboard. The entire spine should be evaluated, as noncontiguous spinal trauma occurs in 19% of patients with cervical spine injuries (8% cervical, 8% thoracic, and 6% lumbar) [2, 3]. Further, patients with cervical spine trauma should undergo a complete trauma team evaluation, as 57% of these patients present with extraspinal

K. R. O'Neill
OrthoIndy, Inc., Indianapolis, IN, USA

M. S. Shen
Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA

J. E. Bible
Department of Orthopedics, Penn State Milton S. Hershey Medical Center, Hershey, PA, USA

C. J. Devin (✉)
Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA
e-mail: Clinton.devin@vanderbilt.edu

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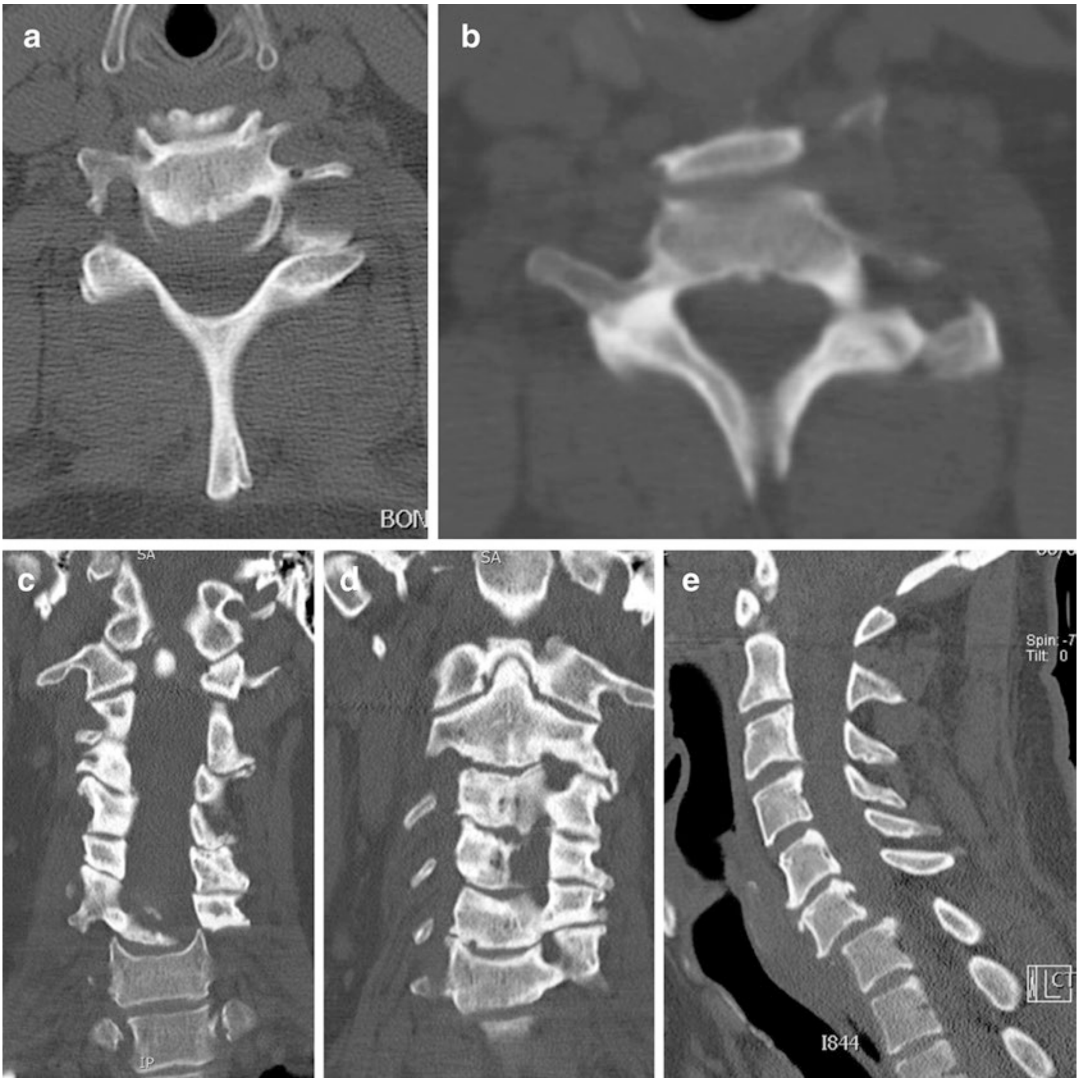

Fig. 3.1 (**a, b**) Axial CT of the spine. (**c, d**) Coronal CT of the spine. (**e**) Sagittal CT of the spine

injuries (34% head and neck, 17% intrathoracic, 10% intra-abdominal/pelvic, and 30% nonspinal orthopedic conditions) [2].

The standard Advanced Trauma Life Support protocol supports the use of plain radiographs as a screening tool with computed tomography (CT) employed as an adjunct. Recent evidence suggests that obtaining a helical CT alone (sensitivity 98%) is superior to the previous protocol (sensitivity 45%) [4]. In a meta-analysis of 14,327 patients from 7 studies, a helical CT alone had greater than 99.9% sensitivity and specificity for detecting unstable cervical spine injuries in trauma patients [5]. The additional use of magnetic resonance imaging (MRI) provides valuable information in evaluating for intervertebral disk and posterior ligamentous complex (PLC) disruption, spinal cord compression, and intraparenchymal injury [6]. A fat-suppressed T2-weighted sagittal sequence has been shown to be a highly sensitive, specific, and accurate method of evaluating PLC injury [7].

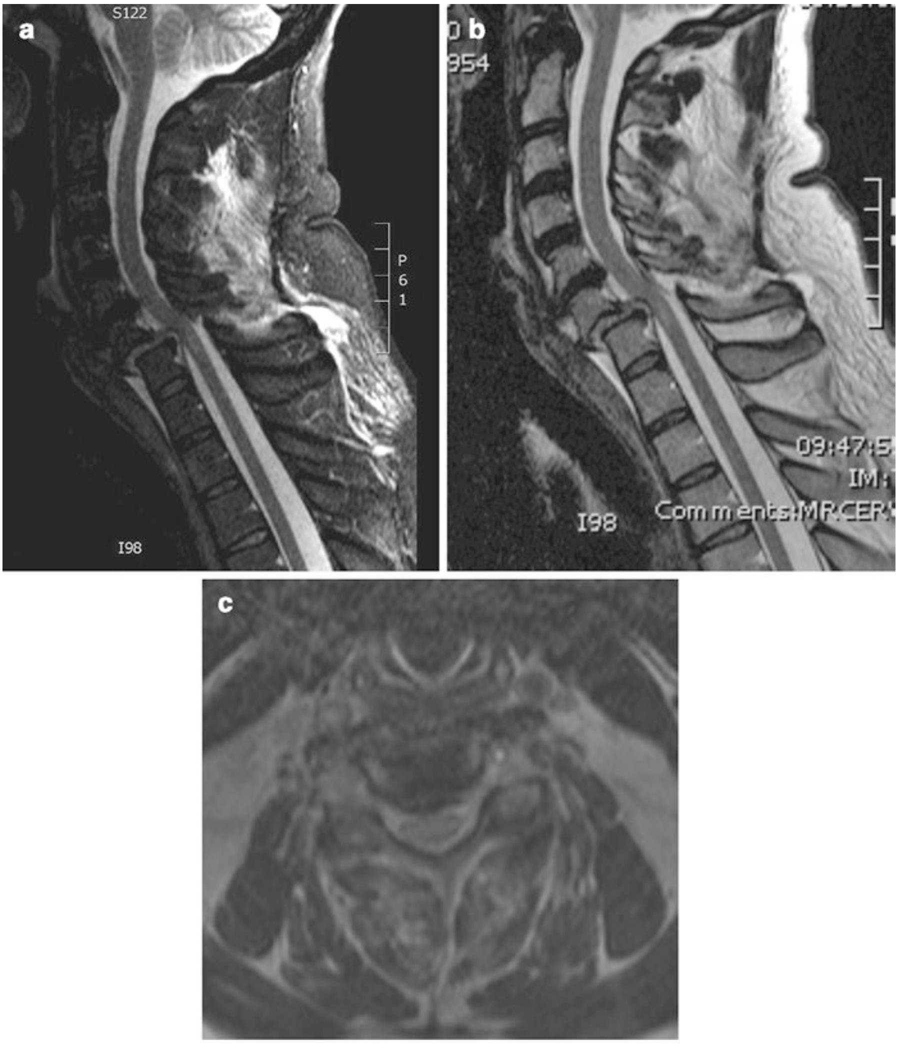

Fig. 3.2 (**a**) T1 sagittal MRI of the spine. (**b**) T2 sagittal MRI of the spine. (**c**) T1 axial MRI of the spine

Neurologic assessments of motor and sensory function are made according to American Spinal Injury Association (ASIA) guidelines. Spinal cord injuries are classified according to ASIA guidelines as follows [8]:

A. Complete: no sensory or motor function is preserved in sacral segments S4–S5.
B. Incomplete: sensory, but not motor, function is preserved below the neurologic level and extends through sacral segments S4–S5.
C. Incomplete: motor function is preserved below the neurologic level, and more than half of the key muscles below the neurologic level have muscle grade less than 3.
D. Incomplete: motor function is preserved below the neurologic level, and more than half of the key muscles below the neurologic level have muscle grade greater than or equal to 3.
E. Normal: sensory and motor functions are normal.

Cervical spine injuries have historically been classified based on the presumed mechanism of injury as determined by utilizing plain radiographs. However, this classification scheme does not provide information relating to stability of the injured spine and therefore is less useful in determining treatment. A more recent classification, the subaxial injury classification (SLIC), has been developed that assesses subaxial cervical spine trauma based on injury morphology, integrity of the discoligamentous complex, and neurologic status of the patient [9]. Points are awarded for each component, and the total score can be used to help guide surgical versus nonsurgical treatment.

This patient presents with a C6–C7 bilateral facet dislocation with incomplete ASIA grade B C5 spinal cord injury. The sagittal CT image (Fig. 3.1a–e) demonstrates 50% anterolisthesis of C6 on C7. Axial and sagittal MRI images (Fig. 3.2a–c) demonstrate a disrupted C6–C7 discoligamentous complex. There is retropulsion of disk material causing cord compression. Increased signal within the spinal cord at this level can be seen on the T2 image sequences. There is complete disruption of the PLC. This injury would be classified as a flexion-distraction injury with a SLIC total score of 8, indicating likely a need for surgical stabilization.

Declaration of Specific Diagnosis

This patient presents with a C6–C7 bilateral facet dislocation with an incomplete C7 spinal cord injury secondary to fall.

Brainstorming: What Are the Treatment Goals and Options?

Treatment Goals:

1. Reduce the dislocation.
2. Provide cervical stabilization.
3. Minimize secondary spinal cord injury.
4. Maximize potential for neurologic recovery.

Treatment Discussion and Options:

1. Optimal medical management
2. Closed reduction and external orthosis
3. Open posterior reduction and fusion
4. Open anterior discectomy, reduction, and fusion
5. Combined anterior and posterior reduction and fusion
6. Intraoperative considerations:
   (a) Positioning
   (b) Neurophysiological monitoring

Evaluation of the Literature

In order to identify relevant articles in the treatment of this patient with a cervical facet fracture-dislocation and spinal cord injury, PubMed searches were conducted on articles published between 1975 and the present. Search headings included "Cervical Vertebrae," "Spinal Injuries," and "Spinal Cord Injuries." This search yielded 496 abstracts in the English literature. These abstracts were reviewed, and relevant articles were selected. Select references from these articles were also reviewed, and relevant articles were also included. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

Medical Management

Medical management of spinal cord injuries is directed at mitigating secondary injury and starts with maintenance of spinal cord perfusion [10]. Maintenance of mean arterial pressures greater than 85 mmHg has been shown to improve neurological outcome [11]. This generally requires invasive hemodynamic monitoring in an intensive care setting and may require intubation.

A variety of pharmacologic agents have been investigated for use in spinal cord injuries in an attempt to mitigate secondary injury and improve neurological outcome. However, no such agent has been found to be clinically effective. The use of steroids remains controversial as the three National Acute Spinal Cord Injury Study (NASCIS) trials [12–14] have been widely criticized for errors of randomization, clinical endpoints, reliability of data collection, and definitions of functional motor levels [15, 16]. In a meta-analysis combining the NASCIS studies with others that investigated steroid use in spinal cord injury, the use of steroids was found to remain unproven and experimental [17].

Hypothermia has also been investigated, as it slows basic enzymatic activity and reduces energy requirements, and therefore may have a neuroprotective effect. Animal studies of acute traumatic spinal cord injury have yielded inconclusive results [18]. Although systemic hypothermia may hold some increased risks of coagulopathy, sepsis, and cardiac dysrhythmia, the only clinical trial thus far found no difference in complications between 48 h of 33 °C intravascular hypothermia and control groups [19]. However, little can be concluded from the 14 complete cervical spine injury patients included in this phase 1 trial, of which only 3 were ASIA C or higher at final 1 year follow-up. In a case-controlled study of 35 acute cervical SCI patients who received 33°C intravascular hypothermia for 48 h, results were promising in terms of safety and improvement of neurological outcomes [20]. Still, a multicenter, prospective, randomized study is required to better determine the efficacy of this method.

Conservative Management

Closed Reduction and Magnetic Resonance Imaging

It is important to relieve spinal cord compression as soon as possible. Immediate closed reduction using skeletal traction with sequentially increased weight is usually effective in restoring cervical alignment [21, 22]. However, closed reductions can result in increased disk herniation [23]. The risk of significant neurologic deterioration resulting from this is rare [24]. A prereduction MRI has been advocated in patients with an unreliable exam due to altered mental status. The main concern is identifying disk material in the spinal canal that may cause increased cord compression and potential further neurological deterioration, following a closed reduction [25]. Others believe that this risk is so low that the delay of obtaining an MRI prior to reduction is not warranted [21].

The mental and neurological status of the patient should be considered in this decision. In an awake and alert patient who has an intact or an incomplete injury, a closed reduction can safely be performed, provided that a contraindication to traction does not exist. The main contraindications to the use of a closed reduction attempt in this population are a skull fracture and concomitant upper cervical dislocation [23]. If neurologic deterioration occurs during the reduction attempt, the traction should be discontinued and an open reduction performed. If an awake exam is not possible or the patient is in spinal shock, neurologic deterioration resulting from traction would not be recognized. Prereduction MRI may be useful in these cases to evaluate for extruded disk material that might cause such deterioration following a closed reduction. If the patient has a complete injury, there is no risk of further deterioration, and an immediate closed reduction should be performed.

External Orthosis

Bilateral facet fracture-dislocations are unstable injuries and are best treated with operative fixation. As such, there are no data available regarding conservative treatment with orthoses of these injuries. However, it is useful to consider available evidence in the treatment of unilateral facet fracture-dislocations. In a retrospective review of 34 patients with unilateral facet dislocations or fracture-dislocations, the surgical group ($n = 10$) in comparison with a nonoperative group ($n = 24$) was found to be more likely to attain anatomic reductions (60% vs. 25%) and bony fusion (100% vs. 46%) and less likely to have significant chronic pain (10% vs. 42%) and translation on flexion-extension views (20% vs. 38%) [26]. However, none of the differences between groups were statistically significant ($p > 0.05$), and the methodology was not clearly described. In another retrospective study of unilateral facet fracture-dislocations, 18 patients treated with a cervical collar or halo had failures related to either inability to hold the reduction or persistent neurologic deficit [27]. Patients treated with posterior reduction and fusion had significantly improved SF-36 PCS scores compared to the nonoperative group [28]. It is reasonable to assume that the benefits of surgery would be even greater in the more unstable case of bilateral facet dislocations.

To help determine whether operative intervention or conservative treatment is indicated, an evidence-based algorithm has been developed based on the SLIC classification [29]. Combining available studies with expert opinion, this study suggested guidelines to help with clinical decision-making. With regard to facet dislocations or fracture-dislocations in particular, 4 points are awarded for the injury pattern and 2 points for disruption of the discoligamentous complex. An additional 4 points would be allotted based on the neurologic status of the patient, with surgical treatment being recommended for scores greater than 5.

Surgical Management

Intubation

Intubation and patient positioning must be carefully considered in cases of unstable cervical spine injuries. Cervical motion should be minimized in order to prevent further injury to the spinal cord. Although in-line intubation is the quickest technique for airway control, it produces significant cervical motion with an average of 22.5° during intubation with a Macintosh laryngoscope. Instead, use of a fiber-optic-guided system and a Bullard laryngoscope should strongly be considered as these produce significantly less cervical motion (5.5 and 3.4°, respectively) [30].

Patient Positioning

It is also important to limit cervical spine motion when turning a patient from supine to prone on the operating table. Although patients can be manually rolled into a prone position, utilization of a rotating Jackson spine table has been shown to result in two to three times less cervical angular motion [31]. In this cadaveric study, cervical motion was significantly reduced in all three motion planes compared to the manual method. Additionally, use of a cervical collar during these maneuvers was shown to significantly reduce motion.

Neuromonitoring

Intraoperative neuromonitoring (IOM) is commonly used in order to avert complications and optimize outcomes. In one retrospective study, IOM was shown to be helpful in preventing a postoperative deficit in 5.2% of patients [32]. Somatosensory-evoked potentials (SSEPs), in which the distal extremities are stimulated and recordings are made at the scalp, provide continuous intraoperative assessments of dorsal column sensory pathways. In ideal situations, SSEPs can require 5 min to detect neurologic changes. Transcranial motor-evoked potentials (tcMEPs), where cranial stimulation is provided and compound motor action potentials (CMAP) are recorded in distal muscle groups, assess motor pathways. Motor-evoked potentials detect a change much quicker due to the higher metabolism rate of the anterior horn cells. The combination of tcMEPs and SSEPs permits assessment of both ascending sensory and descending motor pathways.

Preposition and postposition neuromonitoring are commonly performed to ensure that there is not a neurological change during positioning. Additionally, unless a complete neurological injury exists with no SSEPs or MEPs detected, continuous intraoperative monitoring is commonly performed. If a significant change is detected (SSEP amplitude decreases >50% or MEP amplitude decreases >75%), then the first step should be to elevate the mean arterial pressure and ensure that the patient is adequately oxygenated, followed by removal of hardware and assessment of inadequate decompression if there is no improvement.

Surgical Timing

There has been considerable interest in determining the optimal timing of surgical decompression following spinal cord injury. Current literature seems to provide support for early (<24–72 h) surgical decompression [33–35]. A multicenter, prospective cohort study, the Surgical Timing in Acute Spinal Cord Injury Study (STASCIS), was performed to determine the effects of early versus delayed decompression for traumatic cervical spinal cord injury. In the study, 313 patients with acute cervical SCI were included. One hundred eighty-two had early surgery with a mean of 14.2 ± 5.4 h, and 131 had delayed surgery with a mean of 48.3 ± 29.3 h. After adjusting for preoperative neurological status and steroid administration, there were 2.8 times higher odds of at least a 2 grade AIS improvement for those who underwent early surgery as compared to those who underwent delayed surgery [36]. Although the STASCIS study supports early decompression and stabilization, the demographics of the cohort were variable, and the results should be interpreted within the scope of this limitation.

In an evidenced-based review, 19 papers were identified involving animal models of SCI. In 11 of these studies, improved outcomes were found with early surgical decompression. Additionally, 22 clinical studies were evaluated. Drawing conclusions from these studies regarding the effect of early decompression is complicated by the various definitions of "early" in the literature, which ranged from 8 h to 4 days. However, none of the studies demonstrated increased complications or a worse clinical outcome with early surgery in the medically stable patient. Several studies demonstrated improved outcomes in groups treated with early decompression, with shorter hospitalization, shorter length of ICU care, decreased mortality, decreased complications, and improved neurologic outcome. Based on this review, it was concluded that patients with acute SCI can safely undergo early decompression once medically stable, with the potential for improved neurological outcome.

Surgical Approach

In the absence of a herniated disk at the level of dislocation, a facet dislocation or fracture-dislocation can be reduced and stabilized using either an anterior or posterior approach. Available literature does not indicate a clearly superior approach [37]. In a prospective study of 52 patients with spinal cord injury and unstable subaxial cervical spine injuries, no difference was found when comparing anterior and posterior approaches in terms of fusion rates, alignment, neurologic recovery, or long-term complaints of pain [38]. All patients in this study received MPSS and had a closed reduction prior to surgery.

Radiographic failure and loss of reduction may occur more often using an anterior approach alone. In a retrospective radiographic review of 87 patients with either unilateral or bilateral facet dislocations or fracture-dislocations treated with anterior cervical discectomy and fusion (ACDF) using a static anterior plate, 13% demonstrated radiographic failure defined as translation of at least 4 mm or increased kyphosis of at least 11° [39]. In contrast, in another retrospective radiographic review of 65 patients whose facet dislocation or fracture-dislocation was managed with single segment posterior cervical instrumentation (plate or wire fixation) and fusion, 3.5% ($n = 2$) demonstrated radiographic failure [40]. The integrity of the PLC is an important consideration. In a cadaveric biomechanical study using a corpectomy model, anterior fixation with a static plate and PEEK cage was found to adequately stabilize the cervical motion segment provided that that PLC was intact. If the PLC was disrupted, anterior combined with segmental posterior fixation was required to achieve adequate stability [41].

If the dislocation is associated with a herniated disk, an anterior approach is preferred, as the disk can then be directly removed before the reduction is performed [42, 43]. This approach is supported by an algorithm based on the SLIC classification [44]. In one study, various treatment options were compared in patients with facet fracture-dislocations. A retrospective arm consisted of 12 patients treated with hard cervical collar, 6 patients with halo, and 11 patients with posterior fusion using either wire or lateral mass screw and rod fixation. A prospective group of 18 patients treated with ACDF using a static plate and iliac crest bone graft was compared to this cohort [27]. Patients treated with a cervical collar or halo had failures related to either inability to hold the reduction or persistent neurologic deficit. The posterior fusion group had 45% failure due to inadequate reduction ($n = 5$), persistent radiculopathy ($n = 2$), or progressive kyphosis ($n = 3$). The study did not indicate whether these failures occurred with wire versus lateral mass fixation. The anterior fusion group demonstrated 100% success, as defined by the ability to achieve and maintain reduction, maintain neurological status, and prevent the need for secondary surgery. Another retrospective study of 22 patients with bilateral facet fracture-dislocations confirmed these excellent results using ACDF with bone graft and static plate fixation, with all patients demonstrating radiographic union at 32 months follow-up [45].

Literature Inconsistencies

Most of the studies used to drive current treatment strategies related to this case are based on expert opinion, retrospective studies, and underpowered prospective series. More prospective randomized data are needed to better guide decision-making.

Evidentiary Table and Selection of Treatment Method

The key studies in treating MJ are listed in Table 3.1 [17, 27, 33, 36]. Based on the available literature, MJ would undergo an attempted closed reduction immediately. Within 24 h of presentation, she would undergo anterior open reduction and ACDF, followed by posterior lateral mass screw and rod fixation.

Definitive Treatment Plan

The patient would initially be placed in a rigid cervical orthosis and kept in an ICU environment with maintenance of the mean arterial pressure above 85 mmHg. The authors do not believe that clear benefits have been demonstrated by current pharmacologic interventions aimed at improving neurologic recovery. As a result, no such interventions, including steroid administration, would be initiated.

Because the patient is awake and alert, a closed reduction attempt would be initiated as soon as possible with Gardner-Wells tongs in order to minimize the time of cord compression. Ten pounds of traction would initially be applied, followed by the incremental addition of 10 pounds until reduction was achieved. After each addition of weight, a neurologic and radiographic evaluation with a lateral radiograph would be performed. Traction would be discontinued if the patient developed worsening neurological complaints, if radiographs demonstrated overdistraction of the injured or adjacent level, or if there was evidence of occipitocervical distraction. Following reduction, the patient would be kept in 20 pounds of traction, and the cervical collar would be kept in place. An MRI would then be obtained to localize any continued areas of cord compression and assist in surgical planning.

Early surgical stabilization would be performed within 24–48 h after injury. An anterior surgical approach would be used in this case because of the herniated disk at the injured level. In the operating room, pre- and postpositioning and intraoperative SSEPs and MEPs would be obtained. A lateral fluoroscopic view would be taken prior to prepping and draping to insure adequate visualization. The mean arterial pressure would be kept above 85, and careful attention would be given to maintaining oxygenation.

A standard anterior cervical discectomy and fusion would be performed. Caspar pins would be asymmetrically placed in a divergent manner to facilitate the reduction and disk removal. An autograft or allograft would be placed in the disk space taking care not to overdistract, and a static anterior plate would be applied. Given that there is injury to the PLC, the patient would be turned to a prone position with posterior segmental fixation and fusion with autograft or allograft (Fig. 3.3a, b). If a reduction was unsuccessful from an anterior approach, the disk space would

Table 3.1 Evidentiary table: A summary of the quality of evidence for treatment of cervical spine fracture-dislocation

Author (year)	Description	Summary of results	Level of evidence
Hurlbert (2001) [17]	Meta-analysis	Meta-analysis combining results of nine studies on effects of steroids in acute spinal cord injury, showing steroids to have known risk and unproven benefit	I
Furlan et al. (2011) [33]	Meta-analysis	19 animal studies and 22 clinical studies included on the timing of surgical decompression in spinal cord injury, suggesting early decompression within 24 h if medically feasible	III
Lifeso et al. (2000) [27]	Prospective, nonrandomized	18 patients with unstable cervical spine fractures successfully treated with anterior stabilization, compared retrospectively to 11 patients treated posteriorly with 45% failure and 18 patients treated nonoperatively with 100% failure	III
Fehlings et al. (2012) [36]	Prospective cohort study	222 patients with follow-up available at 6 months post injury, 19.8% of patients undergoing early surgery showed a ≥ 2 grade improvement in AIS compared to 8.8% in the latter decompression group (OR = 2.57; 95% CI,1.11,5.97). Odds of at least a 2 grade AIS improvement were 2.8 times higher among those who underwent early surgery as compared to those who underwent late surgery (OR = 2.83; 95% CI,1.10,7.28)	III

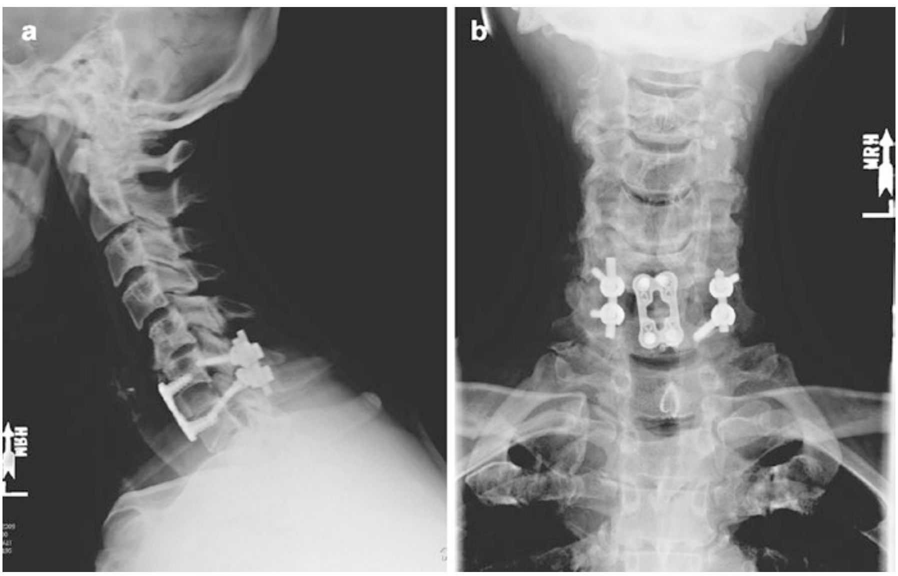

Fig. 3.3 (**a**) Postoperative lateral radiograph of the cervical spine. (**b**) Postoperative AP radiograph of the cervical spine

be left empty, the patient would be rolled into the prone position, and a posterior reduction and stabilization would be performed. The patient would then be rolled back into a supine position for placement of an anterior graft and a static plate. A hard cervical collar would be placed until stability was verified with flexion and extension radiographs. The patient would remain in the ICU to maintain spinal cord perfusion.

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Lumbar Burst Fractures

4

Daniel G. Tobert and Mitchel B. Harris

HS: A 21-Year-Old Man with Severe Low Back Pain After a Fall

Case Presentation

Patient HS is a 21-year-old man who sustained a fall from 20 feet. On emergency medical services (EMS) arrival to the scene, he denied loss of consciousness, had a GCS score of 15, and was brought to the emergency department (ED) for further evaluation. On primary survey, the airway was patent, and hemodynamics were stable. On secondary survey, he complained of severe low back pain, right lower extremity radicular pain, and a sensation that he is unable to urinate.

Pertinent physical examination findings include an alert and oriented mental status. He demonstrates Medical Research Council (MRC) grade 5/5 strength in bilateral upper and lower extremity with normoreflexia. His rectal tone is intact, there is no ankle clonus, and Babinski's test is downward.

Radiographs, CT, and MRI of the lumbar spine are demonstrated in Figs. 4.1a, b, 4.2a–e, and 4.3a–c.

D. G. Tobert (✉) · M. B. Harris
Department of Orthopaedic Surgery, Harvard Medical School, Massachusetts General Hospital, Boston, MA, USA
e-mail: dtobert@partners.org

Interpretation of Clinical Presentation

This case involves an otherwise healthy young man who presents with severe low back pain and right lower extremity radiculopathy after a fall from 20 feet. The height from which patient HS fell is considered a high-energy traumatic mechanism of injury, and a systematic evaluation for life-threatening injuries is warranted. The Advanced Trauma Life Support (ATLS) protocol was developed to rapidly identify life-threatening injuries and allow stabilizing interventions [1]. The primary survey is performed on arrival to the ED to assess airway patency, respiratory status, and hemodynamic stability. Patient HS demonstrated a negative primary survey.

On secondary survey, he complained of severe low back pain and acute-onset right lower extremity pain that was sharp and radiating in quality. A spine-focused secondary survey includes motor and sensory testing of individual muscle groups. The American Spinal Injury Association (ASIA) provides a detailed work sheet that is helpful to ensure a comprehensive examination is performed [2]. The logroll maneuver is an essential component of the secondary survey. At this time, the clinician can inspect the dorsal spine anatomy and palpate the length of the spine for tenderness, step-offs, crepitus, or gaps between spinous process to alert for a potential spinal ligamentous injury. The logroll maneuver also provides an opportunity to

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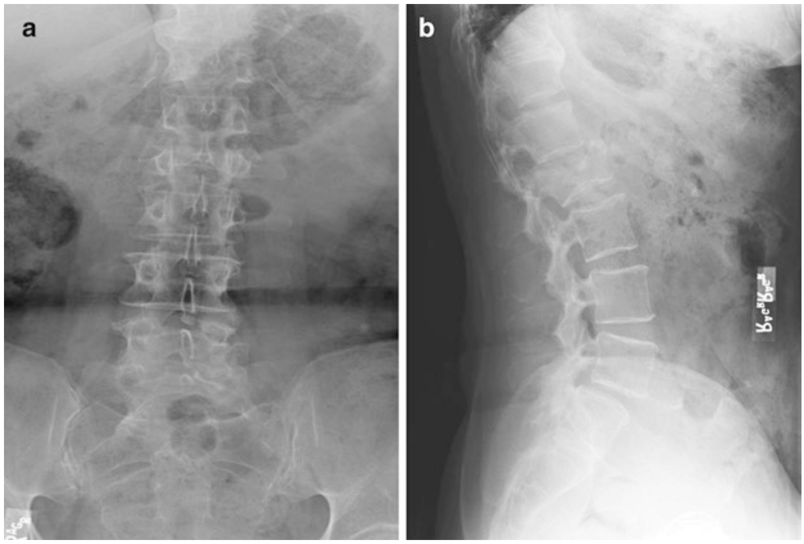

Fig. 4.1 (**a**) AP radiograph of the lumbar spine. (**b**) Lateral radiograph of the lumbar spine

perform a rectal examination to assess external anal sphincter tone and perianal sensation.

The pertinent findings for patient HS thus far include severe low back pain and right lower extremity symptoms consistent with radiculopathy. The location of his pain and symptoms raises concern for injury to the low thoracic or lumbar spine. A secondary survey did not reveal additional injuries in patient HS, but a thorough secondary and tertiary survey is required as concomitant injuries are common [3]. Although this was not the case with patient HS, concomitant injuries can have a distracting effect on spine injuries, which highlights the importance of a careful spine exam during the secondary survey [4].

The right lower extremity symptoms described by patient HS are suspicious for radiculopathy. If possible, the distribution of the symptoms should be clarified with the patient as medial thigh pain is consistent with upper lumbar nerve root pathology and lateral/posterior thigh distribution is consistent with low lumbar/upper sacral nerve root involvement. This clinical information can be correlated with future imaging studies. There are no motor deficits on examination, but his exam should be documented on presentation and repeated serially to rule out an evolving neurologic deficit. Progressive neurologic dysfunction is an indication for urgent surgical intervention [5].

The sensation of inability to urinate can have myriad etiologies in the trauma setting. Pain, narcotic analgesia, and supine positioning all contribute to a patient's subjective feeling of retention. More concerning is a neurogenic etiology and must be considered in light of the injury mechanism and location of symptoms. The spinal cord terminates at the conus medullaris (CM), which is generally at L1 but can vary between T11 and L2. The conus medullaris contains the cell bodies of the sacral nerves and axons surrounded by the traversing lumbar nerve roots, which exit the spinal cord as high as T10 and form the cauda equina (CE). Volitional voiding is regulated by complex neural pathways and reflexes, which are comprised of sympathetic, parasympathetic, and somatic components [6]. Therefore, injury to the sacral cell bodies or sacral nerve roots prevents both detection of bladder distention and detrusor contraction, resulting in overflow incontinence. A loss of perianal pinprick sensation and external anal sphincter tone often accompanies a CE or CM syndrome. In the absence of other symptoms, CE or CM syndrome is unlikely in the case of patient HS. However, a bladder scan should be performed, and if greater than 500 mL, a Foley catheter should be placed.

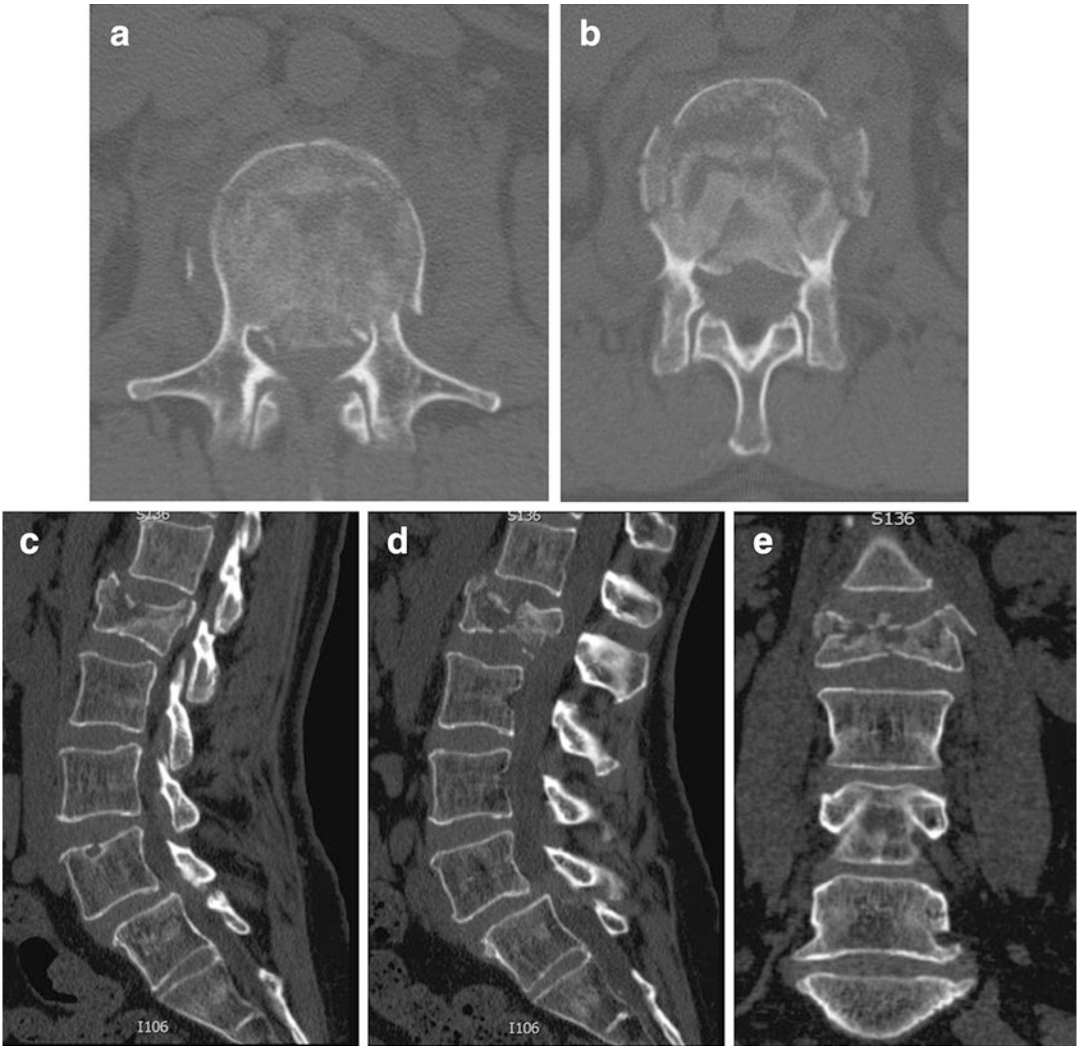

Fig. 4.2 (**a, b**) Axial CT of the spine. (**c, d**) Parasagittal CT of the spine. (**e**) Coronal CT of the spine

Interpretation of Radiographic Imaging

Thoracic and lumbar fractures comprise 50% of all vertebral column fractures [7]. Fractures of the thoracolumbar junction represent up to 20% of spinal fractures, in comparison with <5% for low lumbar (L3–L5) region fractures. The indications for obtaining imaging in a patient who sustains blunt-force trauma include back pain, point tenderness, altered mental status, and distracting injury [8]. Plain film radiography previously was the screening modality of choice for thoracolumbar injury. However, Sheridan and associates demonstrated plain films can miss up to 48% of thoracic injuries and 14% of lumbar injuries [9]. Currently, radiographic work-up of high-energy blunt-force trauma victims typically includes multi-detector computed tomography (MD-CT) of the head, cervical spine, chest, abdomen, and pelvis. Herzog and associates demonstrated the superiority of MD-CT over plain films for detecting spine injuries, especially with 3-mm axial slices and reformations [10]. Berry and associates confirmed this finding, and in 2012 the Eastern Association for the Surgery of Trauma (EAST) published a strong

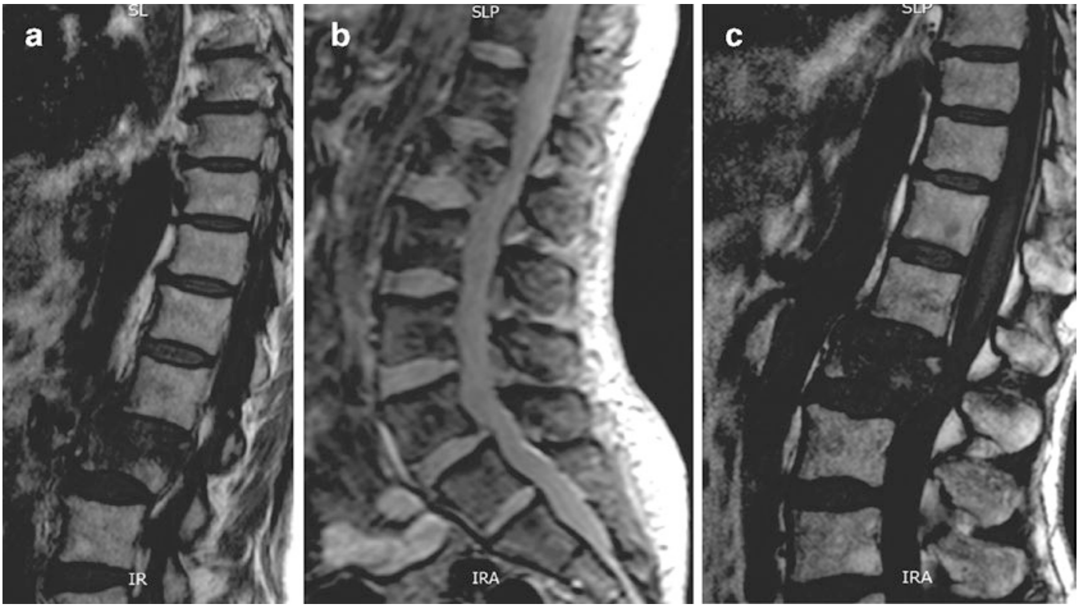

Fig. 4.3 (**a**) T1 parasagittal MRI of the spine. (**b**) T2 parasagittal MRI of the spine. (**c**) Parasagittal MRI of the spine

recommendation for MD-CT as the primary screening modality for thoracolumbar injuries secondary to blunt trauma [8, 11].

The incidence of non-contiguous fractures of the spine warrants imaging of the entire spine if an injury is found [12]. While not mentioned specifically in the case vignette for patient HS, cervical spine clearance should be initiated (see Chap. 2), and the presence of a lumbar fracture warrants screening the cervical spine with MD-CT.

Magnetic resonance imaging (MRI) does not play a role in the primary screening for thoracolumbar injuries. MRI is an inferior modality when assessing the osseous structures of the spine and should be used as an adjunct to MD-CT. The indication for MRI in the acute setting is reserved for a scenario where neurologic deficits exist in the absence of radiographic injury. MRI helps visualize the soft tissue structures, including the posterior ligamentous complex (PLC), but should be obtained by the consulting spine service [13].

Figure 4.1a, b show a thoracolumbar burst fracture. Careful attention to the radiographs shows a lumbarized sacral segment. To frame this discussion, the first vertebra without a rib will be designated L1. Therefore, patient HS's burst fracture occurred at L2. The AP radiograph shows widened interpedicular distance at L2, which is consistent with a burst fracture pattern. On the lateral radiograph, the L2 vertebral height is approximately 50% of the adjacent body's height. The lateral radiograph also reveals the sagittal alignment of the thoracolumbar junction without physiologic loading. The normal anatomic sagittal cascade of the thoracolumbar junction demonstrates a transition from thoracic kyphosis to lumbar lordosis. A Cobb angle measured from the superior end plate of the cephalad vertebra (L1) to the inferior end plate of the caudal vertebra (L3) demonstrates a roughly neutral normal alignment through the fracture segment. Further observations of the lateral radiograph show Meyerding grade 1 anterolisthesis of L5 on S1, although this is likely an incidental finding.

The MD-CT images in Fig. 4.2a–e confirm the loss of height observed on plain film and further delineate fracture morphology. Figure 4.2a shows a retropulsed fracture fragment obscuring approximately 40% of the spinal canal in the axial plane. Figure 4.2d shows involvement of both superior and inferior end plates of L2. The facet joints remain reduced, and there is no clear fracture involving the posterior structures, but thorough review of all MD-CT images would help confirm this observation. The MRI images provided (Fig. 4.3a–c) show the spinal cord terminates at L1, and there is canal narrowing at the level of the L2 vertebral body but no myelomalacia of the conus medullaris. The PLC structures (ligamentum flavum, interspinous ligament, supraspinous ligament, and zygapophyseal joint capsules) appear intact.

Declaration of Specific Diagnosis

Patient HS is a 21-year-old man who sustained a fall from 20 feet found to have an isolated L2 burst fracture with resultant radiculopathy, intact motor function, and indeterminate neurogenic bladder.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals include:

1. Prevent further neurologic injury and optimize neurologic recovery.
2. Ensure fracture union with adequate sagittal alignment.
3. Allow rapid mobilization.
4. Minimize acute and chronic pain.

Treatment options include:

1. Non-operative treatment:
   (a) With brace
   (b) Without brace
2. Operative treatment:
   (a) Posterior approach:
      (i) Long segment fusion
      (ii) Short segment fusion
      (iii) Instrumentation without fusion
   (b) Anterior approach.

Evaluation of the Literature

A PubMed search was performed to identify relevant scientific literature. Search terms included "thoracolumbar," "burst," and "fracture." The search retrieved 696 abstracts, which were reviewed, and 102 articles were read. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Classification Systems for Thoracolumbar Trauma

The first classification system for thoracolumbar injuries was described by Boehler in 1929. Nearly every decade since then, a new classification system has emerged, which underscores the challenge of creating a comprehensive and reliable framework that simultaneously facilitates clinical decision-making [14]. Whitesides introduced the concept of stability in 1977 and argued that intact posterior elements and ligaments would provide rotational stability for a burst fracture to heal [15]. In 1983, Denis published the "three-column" paradigm and argued the middle column integrity was an important determinant of stability [16]. McCormack and associates published the load sharing classification in 1994, which aided clinical decision-making and was relatively simple to use but ultimately not comprehensive enough [17]. In contrast, the AO/Magerl system divides thoracolumbar fractures into types A, B, and C with further subtypes yielding 53 unique fracture types [18]. While comprehensive with regard to fracture pattern, this classification system omits neurologic status and is limited by both inter- and intra-observer reliability [14].

The Thoracolumbar Injury Classification and Severity Score (TLICS) provides a numerical score based on fracture type, neurologic status, and PLC integrity [19]. A combined score of 3 points or less recommends non-operative treatment, a score of 5 or more indicates consideration of operative treatment, and a score of 4 is equivocal. Lewkonia and colleagues showed good interobserver reliability for TLICS in a study involving 54 thoracolumbar injuries and 11 surgeons, with determination of PLC integrity having the least agreement [20]. The variance in PLC determination and the possibility of certain fracture types (such as severely comminuted burst fractures) receiving a score incommensurate with severity are criticisms levied against TLICS [21].

To address concerns regarding TLICS, the AO/TLICS algorithm was developed [22]. This system synergistically links AO/Magerl and TLICS and includes an expanded scale for neurologic status as well as patient-specific modifiers. It should be noted that this scale recognized the inherent biomechanical differences between the thoracolumbar spine and other regions (upper thoracic spine, low lumbar spine (L3–L5), and lumbosacral junctions), suggesting it should only be applied to thoracolumbar fractures [23]. To apply AO/TLICS to the injury sustained by patient HS, a burst fracture involving both endplates is classified A4, symptoms of radiculopathy scores N2, and he does not qualify for modifiers (M0). Recently, the AOSpine Trauma Knowledge Forum published a treatment algorithm to accompany the AO/TLICS system [24]. This survey study reported the treatment preferences of 483 AOSpine members across all 6 AO regions for controversial thoracolumbar injury patterns. The authors acknowledge that firm treatment recommendations are not available for all A3 and A4 fracture subtypes. Interestingly, over 75% of respondents from Europe, South America, and Africa would treat an A4N2M0 fracture surgically. However, only 36% of North American AOSpine members chose surgical treatment.

Non-operative Treatment

The optimal treatment for stable thoracolumbar fractures in patients without neurologic deficits has been the subject of much research in the past three decades. In Whitesides' 1977 description of stable and unstable burst fractures, he recommends operative treatment for stable burst fractures only with concomitant neurologic deficit or kyphosis concerning for "anticipated secondary postural difficulty" [15]. However, in 1984, Denis published a retrospective comparative study of 52 neurologically intact patients with burst fractures treated operatively and non-operatively. He found operative treatment led to better function and a new neurologic deficit in 17% of the non-operative cohort [25]. While this was an alarming rate of neurologic deficit, Mumford and colleagues subsequently found a new neurologic deficit in only 2.4% of patients treated non-operatively [26]. Additionally, this study demonstrated that up to 2/3 of the retropulsed osseous fragments are resorbed at 1 year using serial CT imaging.

Wood and colleagues published a prospective randomized trial comparing operative and non-operative treatment in stable burst fractures without neurologic deficit and found no difference in functional outcomes and return to work but a higher complication rate in the operative cohort [27]. Recently, a study performed on the same cohort with 16–22 years follow-up revealed significantly better pain and function in the non-operative group with equivalent post-traumatic kyphosis between the two groups [28]. This level 1 evidence with long-term follow-up suggests stable burst fractures without neurologic deficit should be treated non-operatively. Additionally, Aras and colleagues demonstrated significant cost savings when stable burst fractures were treated non-operatively [29].

Non-operative treatment for stable burst fractures in the presence of neurologic deficit has not been studied as extensively. Dai and colleagues argue that a limited role exists for conservative treatment based on retrospective data showing the majority of 22 patients with neurologic deficit regained substantial neurologic function with non-operative treatment [30]. Nonetheless, criteria for non-operative treatment in the presence of a neurologic deficit were not revealed by this study. Therefore, a persistent neurologic deficit due to neural tissue compression remains the most compelling indication for operative treatment in biomechanically stable burst fractures.

The thoracolumbar-sacral orthosis (TLSO) brace was employed as an adjunct to non-operative treatment of stable burst fractures [31]. Early ambulation with bracing represented a positive transition from bed rest, which was the previous treatment recommendation. The well-known morbidities of bed rest were avoided by mobilizing early, and hospital length of stay was substantially reduced. However, the efficacy of immobilizing a stable thoracolumbar burst fracture and preventing kyphotic deformity with an external orthosis is inconsistent. In addition, the availability and cost of a TLSO often delay mobilization. Bailey and coworkers performed a prospect randomized trial involving 96 patients with stable thoracolumbar burst fractures treated with a TLSO or without a TLSO [32]. The results confirmed their preliminary data and showed equivalence between the two groups in terms of pain, function, hospital length of stay, and post-injury kyphosis [33].

In summary, non-operative treatment should be attempted for stable thoracolumbar burst fractures without neurologic deficit. High-quality evidence argues that non-operative treatment leads to better long-term function and TLSO bracing is not necessary for initial mobilization.

Operative Treatment

Although the indications for surgical treatment of thoracolumbar burst fractures have changed over time, instability is the primary reason to undergo surgical treatment. Instability can be categorized as *neurologic* or *biomechanical*. Neurologic instability includes incomplete spinal cord injuries, cauda equina or conus medullaris syndromes, and complete spinal cord injuries. The deficit is most often caused by compression of neurologic tissue, which can occur from fracture fragments or resultant deformity from the fracture. There is little debate that neurologic instability is an absolute indication for surgical treatment. Nerve root injury causes symptoms that can improve without operative intervention and therefore is considered a stable injury.

Multiple definitions for biomechanical instability have existed as the understanding of thoracolumbar burst fractures advances, yet a consensus definition has not emerged [34]. Traditionally, radiographic parameters served as a proxy for biomechanical instability. These include vertebral height loss of >50%, canal compromise >50%, and kyphosis >30° on weight-bearing views. The integrity of the PLC is also used to determine biomechanical stability.[19] A subsequent study did not find a correlation between vertebral height loss and kyphosis with PLC injury [35]. The addition of an "indeterminate" category to the TLICS classification and the resolution of MRI have led to concerns of increased false positives and overtreatment of thoracolumbar injuries [36]. Pizones and coworkers compared the integrity of the individual PLC components on MRI to either intraoperative testing (if treated surgically) or progressive radiographic deformity (if treated nonsurgically). This study reported MRI had a 93% sensitivity for disruption of the supraspinous ligament and 100% sensitivity for ligamentum flavum disruption [37]. A finding of biomechanical instability generally indicates surgical treatment due to the subsequent pain and dysfunction of post-traumatic kyphosis, as well as the more extensive surgical techniques required for correction [38].

Finally, intractable pain preventing mobilization can be a relative indication for surgical treatment. Hitchon and coworkers investigated factors that lead to failure of non-operative treatment in stable, neurologically intact thoracolumbar burst fractures [39]. They reported increased kyphosis, canal compromise, and fracture comminution all correlated with failure of non-operative treatment. The morbidities of prolonged recumbence often outweigh the surgical risks of providing rigid fixation. However, the decision for surgery in this scenario should be made by the patient and family after disclosure of the risks and expected benefit.

Posterior Approach

The posterior approach is most commonly used to surgically treat unstable thoracolumbar burst fractures. The advantages include familiarity with exposure and instrumentation, indirect reduction of the fracture via prone positioning, and ability to decompress the spinal canal. Historically, the debate surrounding a posterior approach centered around short segment versus long segment fixation techniques. Short segment fixation involves pedicle screw and rod constructs incorporating the vertebral body above and below the fractured level, skipping the injured vertebra.

Criticism of short segment constructs cites clinical failures due to the biomechanical vulnerability in comparison with long segment instrumentation [40]. Norton and coworkers performed a biomechanical modeling study, which demonstrated improved construct strength if the fracture level is instrumented in addition to the level above and below [41]. A long segment construct involves instrumenting two to three levels above and below the fractured level and has biomechanical advantages over short segment fixation. Disadvantages to this technique include a loss of motion due to the number of levels fused. To date, definitive evidence does not exist regarding the superiority of long or short segment fixation.

The necessity of fusion during posterior instrumentation is increasingly questioned. Toyone and coworkers provided a 10-year follow-up for patients undergoing short segment fixation with removal of hardware at 1 year. They reported this technique prevented significant post-traumatic kyphosis, long-term back pain, and disc degeneration [42]. Dai and colleagues performed a prospective randomized trial comparing instrumentation with fusion to instrumentation alone with a minimum 5-year follow-up [43]. They reported no significant differences in clinical or radiographic outcomes with less operative time and acute pain due to the lack of autologous bone grafting. Jeon and coworkers published a 2-year follow-up on patients who underwent long segment fixation but short segment fusion, followed by removal of instrumentation [44]. They showed an improvement in pain, disability, and range of motion after instrumentation removal. A meta-analysis investigated percutaneous pedicle screw placement compared to open techniques and concluded there was no significant difference in radiographic parameters and pain but less operative time and blood loss [45].

Anterior Approach

The goal of spinal canal decompression in the setting of incomplete neurologic injury led to the adoption of anterior approach techniques. In 1987, Bradford and coworkers published the results of a retrospective comparison of patients with incomplete neurologic deficits treated either by anterior decompression and strut grafting or posterior decompression and/or instrumentation [46]. In this study, neurologic improvement occurred in 88% of patients treated anteriorly compared to 64% treated posteriorly. Furthermore, 69% of those treated regained normal bowel or bladder function compared to 33% treated posteriorly. Nonetheless, the techniques available for posterior decompression have advanced significantly in the past three decades, and recent high-quality outcomes data primarily comparing anterior and posterior approaches for patients with incomplete neurologic deficits are not available. More recent data suggest that an anterior approach provides better long-term sagittal plane correction than a posterior approach [47, 48].

Therefore, given the lack of high quality data to make a definitive recommendation, a consideration of approach should be made based on fracture, patient, and surgeon characteristics. In the setting of incomplete neurologic injury due to anterior neural tissue compression, the surgeon must preoperatively determine if adequate decompression is possible if approached posteriorly. Furthermore, an anterior approach should be considered in the setting of severe comminution and loss of vertebral body height where maximal restoration of sagittal alignment is desired.

Literature Inconsistencies

High-quality long-term data show that non-operative treatment for this subset of burst fractures leads to superior functional outcomes [28]. Additionally, level 1 evidence suggests bracing should not be used as an initial non-operative treatment method [32]. In instances where operative treatment is indicated, there are no high-quality data to suggest superiority of short segment versus long segment fixation. There continues to be debate in the literature about the role of fusion in burst fractures treated surgically with a posterior approach. However, an increasing body of data is suggesting fusion may not be necessary.

Table 4.1 Evidentiary table: A summary of the quality of evidence for treatment of lumbar burst fractures

Author (year)	Description	Summary of results	Level of evidence
Wood (2015) [28]	Prospective randomized study	15–22-year follow-up. 47 consecutive patients enrolled initially, 37 with data available for long-term analysis. No significant difference in kyphosis but significant differences in pain, Oswestry scores, and Roland and Morris scores	I
Bailey (2014) [32]	Prospective randomized study	Equivalence multicenter non-blinded trial of stable TL burst fxs. 47 pts. enrolled in TLSO group and 49 in no-brace group. No significant difference in Roland and Morris scores, Sf-36, pain, satisfaction, or average kyphosis	I
Dai (2009) [43]	Prospective randomized study	73 patients with burst fractures (LSC < 6) randomized to short segment instrumentation with or without fusion. At minimum 5-year follow-up, no differences in clinical or radiographic outcomes but increased acute pain in fusion group due to donor site	I
Hitchon (2016) [39]	Retrospective cohort study	Identified factors for failing non-operative therapy in 68 patients with stable, neuro intact TL burst fractures. Increased kyphosis, canal narrowing, and load sharing classification score were predictive of failure	III
Dai (2008) [30]	Retrospective cohort study	Retrospective review of patients treated non-operatively for stable thoracolumbar fractures. A subset (22 pts) of the 127-pt cohort had acute neurologic deficits. Of these, 93% experienced improvement, and of those without neurologic deficit, none developed a new deficit	II

Finally, the role of the anterior approach when treating thoracolumbar burst fractures remains opaque. From the existing data, the anterior approach is most beneficial if a posterior approach would provide inadequate decompression in the setting of incomplete neurologic injury or if maximal restoration of sagittal alignment is planned.

Evidentiary Table and Selection of Treatment Method

A select group of studies that help guide treatment are listed in Table 4.1 [28, 30, 32, 39, 43]. For patient HS, with a biomechanically stable L2 burst fracture and radiculopathy but full motor strength, the authors would recommend pain control and early mobilization without bracing as the initial treatment. If the patient was unable to mobilize despite comprehensive analgesic modalities, a prefabricated extension brace would be provided. Upright AP and lateral plain films would be obtained to establish a baseline sagittal alignment and vertebral body height to compare with follow-up films.

Non-urgent surgical treatment would be offered in the following circumstances: (1) persistent immobility secondary to low back pain or radiculopathic pain, (2) development of a neurologic deficit, or (3) progressive kyphosis past 30°. In the setting of an unrelenting radiculopathy or new neurologic deficit, a posterior decompression and short segment fusion would be used to avoid loss of motion. If immobility from persistent fracture pain or worsening deformity indicated surgical treatment, a posterior long segment instrumentation would be performed without fusion to avoid loss of motion. Removal of instrumentation would occur at 12–24 months to prevent construct failure.

Predicting Outcomes

The authors expect patient HS will mobilize using upper extremity support and adequate pain control within 1–2 days of the injury. Normal bladder function is expected, and radiculopathy may persist acutely but is expected to improve in the subacute period. A plan for opioid tapering would be established with the patient to prevent long-term dependence. Approximately 10% of kyphosis progression and an additional 10% of vertebral body height loss are expected in the initial 6–8 weeks post-injury. However, the authors expect the deformity progression to stabilize and the fracture to heal uneventfully.

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Part III

Upper Extremity Trauma

5 Scapula Fractures

Peter A. Cole and Lisa K. Schroder

WT: A 19-Year-Old Male with Shoulder Pain

Case Presentation

WT is a 19-year-old male who presents to the emergency department via EMS complaining of severe shoulder pain after a high-speed motorcycle accident in which he was the helmeted driver. He denies any loss of consciousness. On primary survey, he demonstrates a GCS (Glasgow Coma Score) of 15 and a patent airway and is hemodynamically stable. On secondary survey, he demonstrates severe pain with passive range of motion of the right shoulder, but his exam is otherwise negative.

On physical examination, the patient demonstrates a strong radial pulse in the right upper extremity and 5/5 strength throughout the right arm. He has full painless range of motion in the right wrist and elbow. On examination of his shoulder, he demonstrates ecchymosis over the posterior aspect of the scapula and severe tenderness to palpation. He is not able to tolerate passive range of motion of the shoulder.

P. A. Cole (✉) · L. K. Schroder
Department of Orthopaedic Surgery, Regions Hospital, St. Paul, MN, USA

Department of Orthopaedic Surgery, University of Minnesota, Minneapolis, MN, USA
e-mail: Peter.a.cole@healthpartners.com

Radiographs of WT's shoulder reveal a right scapula neck and comminuted body fracture with multiple ipsilateral rib fractures (Fig. 5.1a, b). Transcapular Y radiograph (Fig. 5.2) and computed tomography imaging with 3D reconstruction confirm this diagnosis and depict a "z"-type deformity of the body of the scapula visualized by the lateral border landmarks of the scapula (Figs. 5.3a, b and 5.4a, b).

Interpretation of Clinical Presentation

The patient's radiographic findings in addition to symptoms and physical examination are consistent with a displaced right scapula neck and comminuted scapular body fracture, which is distinguished by a segmental fracture of the lateral border, and multiple ipsilateral rib fractures. The patient's presentation is typical of many who present with a severe scapula fracture.

The majority of scapula fractures are the result of high-energy trauma such as motor vehicle accidents, which account for 52–70% of such injuries [2, 3]. Though scapula fractures represent only about 1% of all fractures [4], they occur with about the same frequency as distal femur and calcaneus fractures according to recent epidemiologic studies. Isolated scapula fractures are uncommon because it takes great energy to fracture the scapula. Concomitant

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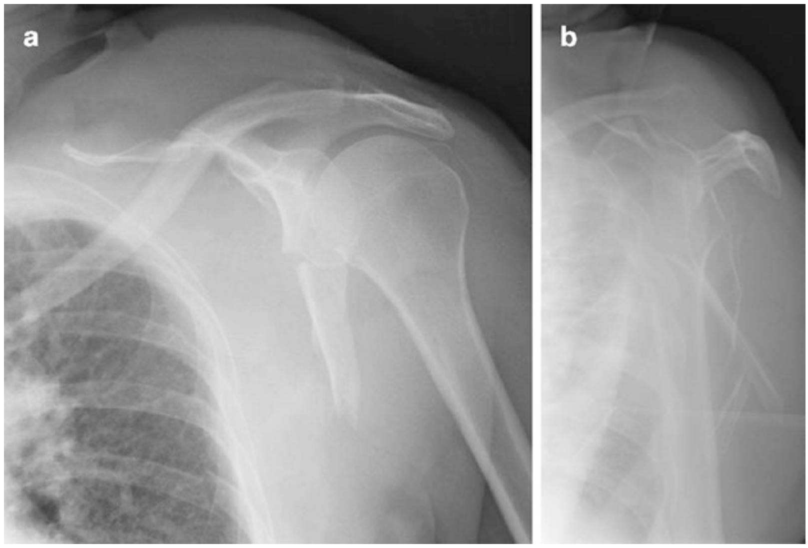

Fig. 5.1 (**a**, **b**) AP (**a**) and scapula Y (**b**) radiograph demonstrate a scapula neck fracture with marked angulation of the scapula body

Fig. 5.2 The angulation and "z" type deformity can be appreciated on the scapula Y radiograph

injuries are estimated to occur in 61–90% of scapula fractures [5, 6]. In addition, up to 53% of scapula fractures are associated with hemo- or pneumothorax [7], and 50% are associated with ipsilateral extremity fractures [5]. Our patient WT is fortunate because another 15% of scapula fracture patients sustain significant head injury [5]. It is imperative that these potentially life-threatening injuries be ruled out when a scapula fracture is detected in the emergency room during initial radiographic studies. A secondary survey, repeated the next day, will be helpful in detecting initially missed injuries. Multiple level rib fractures in WT's case underscore the severity of this trauma (Fig. 5.5a, b).

The patient history should identify a few key items. The first is a review of symptoms to detect other injuries. Concomitant ipsilateral neurovascular injuries are common and demand a careful physical assessment of the brachial plexus and distal extremity perfusion. It is also important to understand the patient's baseline function based on recreation and occupational activities. Since highly displaced extra-articular scapula fractures can manifest with long-term symptoms and functional deficits, the patient should be aware of possible limitations. Overhead loss of motion and muscular fatigue may not be an issue for a 50-year-old sedentary factory inspector, but it may be for the homemaker whose main diversion is tennis at the country club several times a week. The drooped shortened shoulder may bother a body image-conscious person.

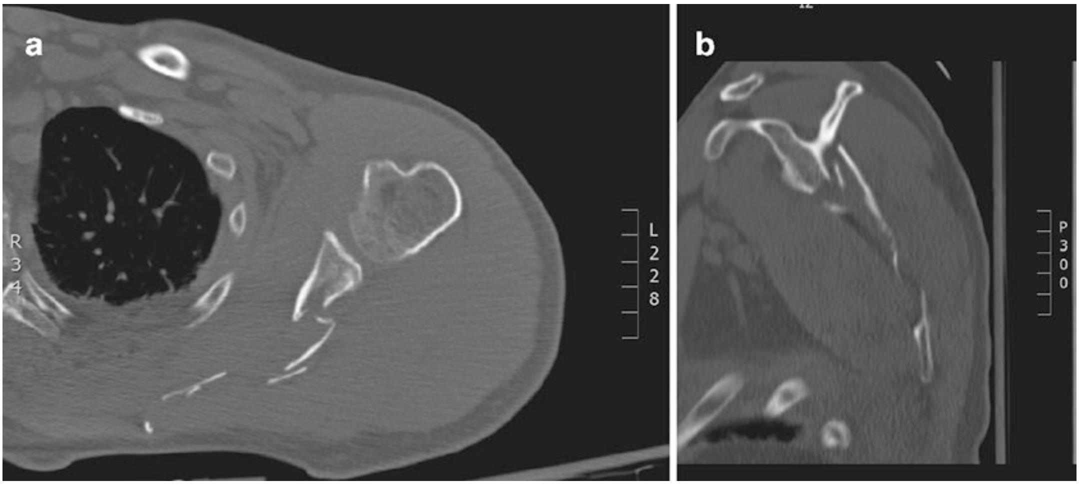

Fig. 5.3 (**a**, **b**) Axial (**a**) and coronal (**b**) CT scan of the scapula fracture clarify the pattern of injury

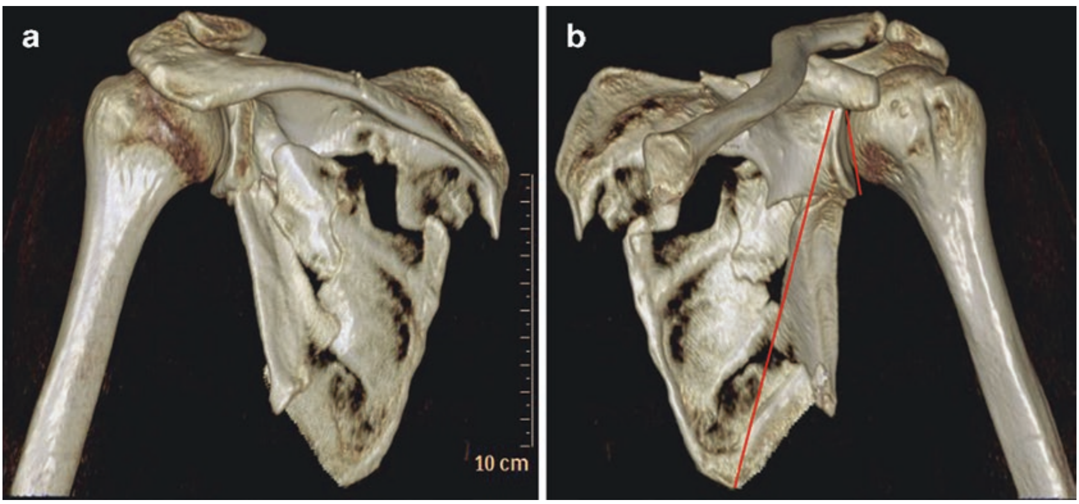

Fig. 5.4 (**a**, **b**) 3D CT reconstruction (**a**) of the scapula. The 3D CT reconstruction is useful to aid in assessment of the glenopolar angle (GPA) and fracture pattern (**b**) (see Ref. 1 for further information). The glenopolar angle (GPA) measured 20° (**b**)

The patient presenting with a scapula fracture should always be disrobed and undergo a thorough secondary survey. A detailed neurological exam, assessment of pulses in the extremities, and a skin check should be performed. Skin abrasions, which occur over the prominent shoulder elements, should also be noted. If surgery is chosen, there should be a delay until reepithelialization occurs to decrease the risk of infection. Our protocol is a simple soap and washcloth cleansing 2–3 times/day until resolved.

Imaging of a scapula fracture should include three radiographic views: an anteroposterior scapula view (Grashey view), an axillary view, and a scapula Y view of the shoulder. Due to the fact that scapula fractures are most often the result of high-energy trauma, 10% are missed or delayed in the primary diagnostic survey [8, 9]. If on plain radiographs there is a displaced fracture which could warrant surgery, then a CT scan should be obtained. Of course the screening spiral trauma CT scan should be reviewed to assess for all

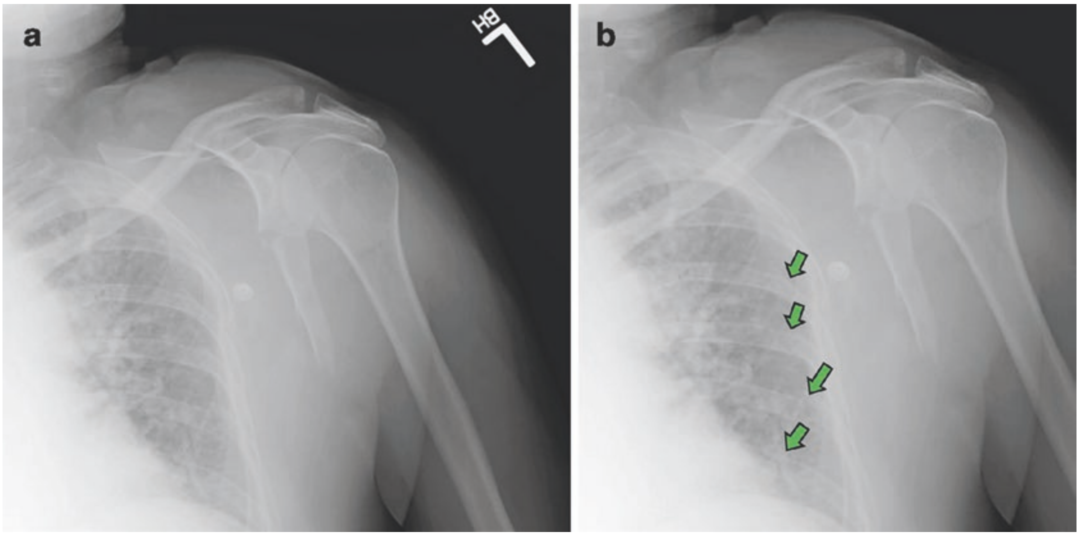

Fig. 5.5 (**a, b**) AP radiograph (**a**) of the left shoulder illustrates the severity of the injury and concomitant rib fractures (**b**) (*green arrows*)

fractures and will detect displaced injuries occasionally missed on screening chest X-ray or shoulder films. This CT modality has been shown to be a much better test, with increased sensitivity for detection [10]. A formal 3D CT reconstruction of the shoulder (or scapula) should be obtained to make accurate measurements of displacement [1, 11]. In addition to the imaging required, in cases where there is a delay of greater than 2 weeks, an EMG-Nerve Conduction Study is recommended to detail any brachial plexus, axillary, and suprascapular nerve lesions which occur with many displaced scapula fractures [12].

Declaration of Specific Diagnosis

WT is a 19-year-old male who presents with a high-energy injury that consists of a right displaced scapula neck (Ada and Miller IIC [13]) and comminuted body fracture, with concomitant multilevel ipsilateral rib fractures.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals are the same as for any other fracture:

1. Restore length, alignment, and rotation.
2. Render stability to allow for rehabilitation.
3. Promote maximal function.
4. Minimize risk and complications.

Treatment options:
Nonoperative:

1. Sling and physical therapy when pain subsides
2. Benign neglect

Surgical:

1. Several posterior surgical approach options
   - (a) Judet incision:
     - (i) With elevation of the entire muscular flap (deltoid, infraspinatus, teres minor)
     - (ii) With elevation of a subcutaneous flap
     - (iii) With or without elevation of the deltoid
   - (b) Intermuscular interval exposure:
     - (i) Between teres minor and infraspinatus
   - (c) Minimally invasive approach:
     - (i) Incisions centered on bony perimeter at the fracture exit locations
2. Fracture reduction
3. Plate and screw fixation

Evaluation of the Literature

A PubMed search was conducted. Keywords included "scapula fracture" and subheadings "surgical treatment" and "conservative treatment," with limits from 1975 to 2011. Eight hundred six abstract entries were reviewed, and from this list, 87 articles were selected. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Review of Pertinent Articles

There are limitations of the existing literature on scapula fractures. Classification systems used continue to be varied, and there is no consensus as to the optimal system. The AO/OTA modified its classification of scapula fractures [14], but few publications with outcomes exist using this classification scheme. Further, the OTA system was developed without clinical or radiographic observations and is flawed by not including combination injuries or all fracture patterns which occur in trauma. Due to these dilemmas limiting clinical applicability, multiple groups have continued work to enhance and validate classification systems, without clear resolution for implementation in today's clinical or research applications [15–17].

Few studies can be compared because of the differences in the descriptive terms dictating the management of the scapula fracture. Authors commonly use descriptors such as displaced, medialized, angulated, and/or shortened; yet these terms have not been defined or validated until very recently [11]. Most literature relies on the Ideberg or modified Ideberg classification [18, 19] for intra-articular fractures as well as the Ada–Miller [13] classification system for extra-articular fractures. The use of computed tomography and the role of 3D reconstruction to aid orthopedists in the understanding of scapula fracture patterns have continued to be recognized as important tools in clinical decision-making and treatment of these injuries [1, 15]. To date, no randomized prospective trials have been published on clinical outcomes of scapula fractures. Furthermore, no studies clearly stratifying clinical outcome as a function of the amount of angulation and displacement have been performed. Rather, there are multiple retrospective studies and single-arm prospective clinical series of operative and nonoperative treatment that describe good outcomes, though clearly subsets of patients in many nonoperative series report some poor and fair clinical results. This data dearth leaves a lack of clear evidence for operative indications. Due to the lack of published evidence, the decision to operate is often based on the surgeon's training and knowledge of surgical approaches as well as the patient's associated injuries, overall physiologic condition, baseline handedness, avocations and occupations, and patient risk tolerance coupled with clinical exam of patient's ability to use upper extremity given current injury. Such surgeons generally apply the rationale which they apply to all other fractures: restoration of length, alignment, rotation, and stability. Below is a discussion of the most pertinent literature.

Conservative/Nonoperative Treatment

The French and others have chronicled the sequence of the diagnosis and surgical management of scapula fractures. Beginning with the first recorded operation in 1913 by Albin Lambotte, contemporary treatment approaches to extra-articular scapula fractures have largely been characterized by benign neglect [20]. In 1984, Armstrong and Van der Spuy documented 62 patients with scapula fractures that were treated nonoperatively [21]. Fractures were stratified simply by fracture location with range of motion being the main outcome assessed. They found good results could be obtained with fractures of the body and spine, while neck and glenoid fractures should be considered for surgery [21]. Bozkurt and colleagues countered that patients with scapula neck fractures could indeed be treated conservatively and that the glenopolar angle (GPA) less than 20° was more indicative of prognosis rather than fracture type [22]. In 1993, Goss theorized that if two or more "breaks" in the superior shoulder suspensory complex (SSSC) occur, it would create an unstable shoulder girdle as a result of the discontinuity between the axial and appendicular skeleton [23]. The theory has been challenged by some authors [24, 25] in that not all double disruptions are unstable and thus do not warrant operative intervention.

Outcomes of minimally to moderately displaced extra-articular fractures managed nonoperatively are good. Van Noort and associates [26] concluded that nonoperative treatment of scapula neck fractures in the absence of neurologic disability and ipsilateral shoulder injury can yield good/excellent functional outcomes, based on 24 patients who had sustained a scapula neck fracture and who all, with the exception of 1, were treated nonoperatively. At follow-up, 13 patients had a functional evaluation and were assessed clinically (as excellent) at an average of 5.5 years after the injury. Gosens and colleagues [27] described the outcomes of 22 patients that sustained scapula body fractures and were managed nonoperatively. Disabilities of the Arm, Shoulder and Hand (DASH) score, the Simple Shoulder Test (SST) score, and the range of motion were the outcomes assessed. There was no effort in this study to measure the amount of displacement nor was there any exclusion criterion for nondisplaced fractures. The mean DASH score of the 22 patients was 17.5, compared with a published normative value for the general population of 10 points. This marginal increase is less than what is considered clinically significant. They further stratified the results to those with isolated scapula fractures and those with multiple injuries ($n = 8$). The mean DASH in patients with multiple injuries was 34.9, and they noted a significant decrease in range of motion compared to the uninjured arm. In another large recent retrospective study, Schofer and colleagues assessed functional outcomes of 51 scapula fractures treated nonoperatively [28]. Seventy-three percent of the fractures were isolated to the body. Again, the degrees of displacement were not assessed, nor were nondisplaced fractures excluded. In addition, the follow-up rate of this study was 37%. The authors reported that 84% of the patients were rated as having good outcomes based on the Constant Score. On follow-up examination, they found restricted range of movement in all directions, lower peak torque values, and lower mean power output in all planes of movement during isokinetic testing. Their conclusion was that scapula fractures heal with a good functional result despite measurable restrictions [28].

Dimitroulias and coworkers [29] published a study early in 2011 using a prospective database of 32 patients treated conservatively for scapula fractures. Only fractures with substantial displacement, defined as a fracture with at least 100% and/or 1 cm displacement, were included in the study. The main outcome was the DASH questionnaire, and no objective measurements such as strength and range of motion were assessed. They reported that the mean increase (i.e., more disability) in DASH from preinjury to final follow-up was 10.2. Noted in this study were the follow-up (65%) and modest numbers of associated injuries (65%) as compared with other scapula fracture literature. The authors did note that a high ISS and presence of rib fractures are associated with a less favorable outcome. While this study does not refute the merits of surgical fixation for severely displaced scapula fractures, it does serve as a testament to the scapula's ability to compensate for displacement and help delineate optimal management of scapula fractures.

Surgical Treatment

As previously stated, minimally displaced extra-articular fractures are best managed nonoperatively. Displaced fractures, however, can disrupt the shoulder's normal mechanisms of stability and motion. Scapula neck malunions have been shown in biomechanical models to shorten the length of rotator cuff muscles, which results in a loss of predicted force as well as altered normal muscle activation during abduction [30]. Furthermore, the compressive force against the glenoid changes to shear forces as a function of the aberrancy of vector [13].

Possibly the greatest support for surgical treatment of displaced scapula fractures has come from suboptimal results of nonoperative treatment. Ada and Miller noted that when they followed 24 patients, managed nonoperatively with displaced, intra-articular, or comminuted scapula spine fractures, significant disability was found in patients with displaced scapula spine and neck fractures: (1) pain at rest in 50–100%, (2) weakness with exertion in 40–60%, and (3) pain with exertion in 20–66% [13]. Nordqvist and coworkers reported that 32% (7/22) of their scapula neck fractures had poor or fair outcomes with 48% (23/48) of all their fractures studied having radiographic deformity [31].

Multiple authors have suggested operative criteria for scapula fractures based upon personal experience and case series outcome reviews [13, 31–33]. Operatively treated extra-articular fracture surgery indications are limited to four reports which define radiologic operative criteria for displacement and angulation [13, 34–36]. Hardegger and coworkers described their operative results for displaced scapula fractures after an average follow-up of 6.5 years [32]. The authors achieved 79% good or excellent results in a series of 37 patients treated operatively, although only 5 cases were included that were "severely displaced or unstable" scapula neck fractures [32]. Bauer and coworkers followed 20 patients who were treated with open reduction and internal fixation (ORIF) of their scapula fracture [3]. They used similar "descriptive" indications recommending ORIF for patients that had grossly displaced acromion or coracoid process fractures, displaced fractures of the anatomical neck, unstable fractures of the surgical neck, and displaced fractures of the glenoid [3]. Several recent key studies collectively suggest a range of indications for surgery [33–38]: (1) ≥4 mm step-off of an articular glenoid fracture, (2) ≥20–25 mm displacement of the glenohumeral joint, (3) ≥25–45° of angular deformity in the semicoronal plane as seen in the scapula Y view, (4) shortening of ≥25 mm, (5) ≥10 mm double lesions of the superior shoulder suspensory complex (SSSC), or (6) GPA ≤ 20–22°.

As controversy and questions remain regarding operative indications, specifically around the utilization of a GPA threshold, several authors have focused attention on the effect of anteroposterior (AP) shoulder radiograph rotational offset causing inaccuracy in the assessment of GPA [39–41]. The authors attempt to quantify the impact of radiographic offset on the true GPA and recommend that GPA be measured on a CT scan with 3D reconstruction [39, 41].

Thus far, the published outcomes after operative treatment seem promising. Most of the data available are derived from smaller retrospective studies, but two systematic reviews offer further support as to the safety of scapular surgery [6, 42]. The review of Zlowodski and colleagues included 22 studies with 520 scapula fractures [42]. Of those operatively treated ($n = 140$), there was a reported infection rate of 3.5% and secondary surgical procedures in 23.5% of the cases reported (8 manipulations under anesthesia, 7 hardware removals, 3 irrigation and debridements, 2 hematoma evacuations, 2 revision fixations, and 1 arthrodesis of the glenohumeral joint). Lantry and coworkers performed a systematic review of 17 studies which included 243 operatively treated scapula fractures [6]. They reported infection as the most common complication (4.2%); however, only one case required repeat surgery for resolution. Lantry and coworkers noted that good to excellent results (using a variety of outcomes) were obtained in approximately 85% of the cases. A 2.4% rate of nerve injury was also noted; however, the authors acknowledged that it was unclear whether these were related to the initial trauma or surgical intervention. More recently, Dienstknecht and colleagues also completed a meta-analysis focusing specifically on operative vs. nonoperative treatment in 463 scapula neck fractures. The authors analyzed a total of 22 manuscripts with 234 of 463 fractures being treated operatively. Though the authors cite the complexity of the patient cohort and the heterogeneity of injury and outcome reporting, importantly, they did find more patients to be pain-free in day-to-day activities in the operative group (OR = 2.77, $p < 0.0001$), but a higher rate of patients with range of motion comparable to the unharmed side in the nonoperative group (OR 0.28, $p < 0.0001$), and an overall rate of postoperative complications of 10.2% [43].

In single-center case series reports, Bartonicek and colleagues utilized an operative inclusion criteria of 100% translation, 30° angular deformity, or scapula fragment penetration through the thoracic wall and reported a Constant Score of greater than 90 points in 19/20 scapula fractures treated surgically [44]. This same group reported longer-term outcomes (mean 4.9 years) in a series of 17 patients specifically with scapula neck fracture variants. Eleven of these were treated operatively due to marked displacement, and the authors concluded that, though minimally displaced neck fractures may be treated nonoperatively, markedly displaced neck fractures are indicated for osteosynthesis [45].

The authors of this chapter have published 3 reports in the recent past, describing early radiographic results in 84 patients undergoing operative treatment of scapula neck and body fractures [46], a report of functional outcomes in 49 of 61(80%) patients having greater than 12 months follow-up describing quantitative strength and range of motion results [47], and also functional outcomes in a geriatric cohort (n = 16) [48]. The first of these reports for 84 operatively treated scapula neck and body fractures having a preoperative mean displacement of 25.7 mm found associated injuries occurring in 94% of the patients. Follow-up was recorded at a minimum of 6 months' postoperatively finding restoration of anatomic or near-anatomic alignment upon radiographic review and 100% union at final follow-up. There were no intraoperative complications nor postoperative infections. Subsequent procedures were deemed necessary in 12 patients [46]. The second report included longer follow-up (mean 33 months, range 12–138 months) with quantitative functional outcomes in 61 patients [47]. The mean DASH score in these patients was 12.1, with mean range of motion results for forward flexion, abduction, and external rotation achieving 96%, 99%, and 97%, respectively, versus the contralateral shoulder range of movement and mean strength results also for forward flexion, abduction, and external rotation achieving 88%, 92%, and 85%, respectively, versus the contralateral shoulder strength. Finally, giving attention to the importance of the growing geriatric patient population experiencing traumatic shoulder injuries and scapula fractures, outcomes in 16 patients aged 65 years and older having high functional expectations and therefore undergoing operative management of scapula fractures were also reported. At a mean follow-up of 40 months, the mean DASH in this cohort was 8.4 with a mean ROM expressed as a percent of the contralateral ROM ranging from 78% to 96% and the mean strength as a percent of the contralateral strength ranging from 76% to 92%.

In 2011, Jones and Sietsema published level III evidence in operative versus nonoperative treatment of displaced scapula fractures. The authors retrospectively reviewed a series of operatively treated scapula fractures and identified a cohort of nonoperatively treated scapula fractures which were matched based upon age, occupation, and gender. In an analysis of rates of union, range of motion, return to work, pain, and complications, they reported no differences, though there were significant differences in all fracture displacement parameters between the two groups. The authors concluded that operative fixation successfully stabilized and restored the anatomy in markedly displaced scapula body and neck fractures resulting in outcomes comparable to nonoperative treatment of less displaced fracture patterns [49].

Because of the high incidence of other injuries, scapula fracture treatment is often delayed. In a retrospective study of 22 patients with an average delay of 30 days before surgery, Herrera and colleagues reported favorable outcomes following surgical intervention [35]. Extra-articular fractures were included in the presence of 15 mm displacement, 25° angular deformity, or double disruptions of the SSSC with 10 mm displacement. Functional outcomes were attained on 14 patients with a mean DASH score of 14; in addition, the injured shoulder had 93% of range of motion and 76% of strength of the uninjured shoulder. From this study, it was noted that the surgery becomes technically more difficult with greater time from injury, but good clinical results could still be achieved.

Surgical management of symptomatic scapula malunions has also been published [50], perhaps providing the most compelling evidence to date regarding deformity and function. Cole and colleagues reported on a cohort of patients that were initially treated nonoperatively and presented with complaints of debilitating pain and weakness. Pre- and post-reconstructive range of motion, strength, and function were all documented and demonstrated significant improvements. Mean follow-up was 39 months (range, 18–101 months), and all five patients were pain-free. The study cohort also experienced a mean improvement in DASH scores of 29 points [50]. However, while it is clear that a minority of patients may experience symptoms following scapula malunion, the incidence of this problem is unknown.

As operative management becomes more common, surgical approaches have been redefined as well. Classically, the most common approach is the posterior (Judet) approach, which utilizes a dissection of the infraspinatus from the infraspinatus fossa [51]. Obremskey and associates further modified this approach to limit muscle dissection to an interval between the infraspinatus and teres minor: to access the lateral border but still allow for fixation of scapula body or neck fractures [51]. At least one study has reported promising early results using this approach [34]. Jones and associates reported on 37 scapula fractures surgically treated with limited windows. The authors reported no infections, hematomas, or dehiscences (incision or muscle). In addition, no complaints of postoperative flap numbness or hypoesthesia were noted.

In 2011, Gauger and Cole introduced a minimally invasive approach to scapula neck and body fractures utilizing strategically placed incisions centered over the fracture sites at the anatomic bony perimeter. The authors reported a series of seven patients treated with mean combined incision lengths of 14.8 cm and 29.2 cm in a group treated through the traditional Judet incision. Results showed all fractures united without malunion, without complications, and patients achieved DASH and SF-36 scores comparable to the reported normative (uninjured) population [52]. As awareness and interest in operative techniques in scapula fracture repair continue to increase, other studies in surgical approaches to the posterior scapula have focused on more soft tissue-friendly techniques while quantifying and optimizing surgical exposure through release of the deltoid [53] or triceps [54] in combination with posterior Judet or modified Judet approaches.

Based on preoperative planning, the surgeon's approach depends on the desire for limited or complete exposure to the posterior scapula. Limited intermuscular windows are favored to spare soft tissue elevation. These are access windows to address fracture displacement at the lateral border, acromial spine, and vertebral border. The extensile approach is used to expose the entire infraspinatus fossa by elevating the infraspinatus and teres minor with an elevator. This muscular flap can be elevated laterally as far as the suprascapular artery and nerve allow without excessive retraction. The posterior glenoid rim, lateral border, neck, spine, and vertebral border are all exposed in this approach. Note that the entire subscapularis–muscular sleeve on the anterior surface of the scapula is preserved, maintaining blood supply to the scapula body. In this context, the approach is biologically appropriate as long as the neurovascular pedicle is respected—a claim substantiated by the presence of only one case of nonunion after ORIF reported in the literature.

It is recommended to utilize an extensile approach for fractures over 2 weeks old or for complex body and neck fracture patterns. The exposure allows the surgeon total control of the fracture at multiple simultaneous sites to effect the reduction and take down intervening callus. It will not allow for exposure of the articular glenoid because the flap cannot be retracted sufficiently to expose the glenoid adequately.

Literature Inconsistencies

The literature on scapula fractures and its management is limited to small retrospective cohort studies. Multiple publications exist with reported surgical indications; however, none of these studies have compared operative versus nonoperative treatment. In addition, no level I or II studies are available to support surgical treatment indications for scapula fractures. Current information is based on retrospective cohorts and systematic reviews. There is a need for prospective randomized control trials or more realistically prospective prognostic studies to further aid in treatment decisions.

Evidentiary Table and Selection of Treatment Method

The key studies to support particular treatment options for our patient WT are summarized in Table 5.1 [6, 13, 21, 22, 24, 26–29, 32, 34, 35, 44, 46–50]. From the current literature, it is the authors' opinion that WT would benefit from operative treatment. The patient meets several of the surgical indications, and early fixation would allow for early and more aggressive rehabilitation.

Definitive Treatment Plan

When addressing a patient with a scapula fracture, the surgeon must look at the radiographic imaging, but also devote attention to the patient's age, associated injuries, and occupation, and take the physical activity level into account. A strong argument can be made that operative intervention would result in improved outcome for WT.

The general indications for surgical treatment of scapula fractures include at least one

Table 5.1 Evidentiary table: A summary of the quality of evidence for nonoperative versus operative fixation after scapula fracture

Author (year)	Description	Summary of results	Level of evidence
Nonoperative			
Armstrong and Van der Spuy (1984) [21]	Retrospective	62 patients, 84% follow-up. Less favorable results with fractures of neck and glenoid. In young and fit patients ORIF may be indicated in these fractures	IV
Ada and Miller (1991) [13]	Retrospective	113 patients, 21% follow-up at greater than 15 months. Indications for surgical management should include some scapula neck and spine fractures	IV
Edwards et al. (2000) [24]	Retrospective	36 patients, 56% follow-up at a mean of 28 months. Floating shoulder injuries are not as unstable as previously thought and may have good functional outcomes with nonoperative treatment of minimally displaced injuries	IV
Bozkurt et al. (2005) [22]	Retrospective	18 patients with a mean follow-up of 25 months. Decreased GPA ≤ 20° may be more reliable than fracture type for dysfunction following scapula fractures	IV
van Noort et al. (2005) [26]	Retrospective	24 patients, 54% follow-up at a mean 66 months. Nonoperative treatment of scapula neck fractures in the absence of neurologic disability and ipsilateral shoulder injury can yield good/excellent functional outcomes	IV
Gosens et al. (2009) [27]	Retrospective	26 patients, 85% follow-up at a mean of 63 months. In scapula fractures with associated injuries functional outcome scores are poorer with conservative treatment versus isolated scapula fractures treated nonoperatively	IV
Schofer et al. (2009) [28]	Retrospective	137 patients, 37% follow-up at a mean of 65 months. Patients managed conservatively after scapula fractures suffer from signification limitations in ROM	IV
Dimitroulias et al. (2011) [29]	Prospective	49 patients, 65% follow-up at a mean of 15 months. Nonoperative treatment may be satisfactory, although increased ISS, and the presence of rib fractures adversely affects the clinical outcome	IV
Operative			
Hardegger et al. (1984) [32]	Retrospective	37 patients, 89% follow-up at a mean of 78 months. Glenoid fracture-dislocations, unstable fractures of the scapula neck, and displaced apophyseal fractures may need anatomical reposition if late disability is to be avoided	IV
Bauer et al. (1995) [6]	Retrospective	25 patients, 80% follow-up at a mean of 73 months. Early operative treatment and understanding of the pathophysiology of the polytrauma patient is critical for displaced scapula fracture management	IV

(continued)

Table 5.1 (continued)

Author (year)	Description	Summary of results	Level of evidence
Herrera et al. (2009) [35]	Prospective registry	22 patients, 73% follow-up at a mean of 26 months. Malunion of the scapula can be prevented by surgical treatment in patients with delayed presentation	IV
Jones et al. (2009) [34]	Retrospective	37 patients, 100% follow-up at greater than 12 months. Modified Judet approach allows for excellent scapula or glenoid fracture visualization while preserving rotator cuff function	IV
Bartonicek & Fric (2011) [44]	Retrospective	22 patients, 100% follow-up at a mean of 26 months. Stable fixation of the lateral boarder is key to restore anatomical relationship of the scapula and obtain good results	IV
Cole et al. (2011) [50]	Prospective	5 patients, 100% follow-up at a mean of 39 months. Corrective reconstruction following scapula malunion can decrease symptoms and improve shoulder function	IV
Cole et al. (2012) [46]	Prospective	84 patients, 88% follow-up at a mean of 24 months. ORIF of scapula fractures is safe and effective in restoration of the anatomy and fracture union	IV
Schroder et al. (2016) [47]	Prospective	61 patients, 80% follow-up at a mean of 33 months. Good functional outcomes are achievable with ORIF in scapula body and glenoid neck fractures	IV
Cole Jr et al. (2017) [48]	Prospective	16 patients, 94% follow-up at a mean of 40 months. Operative treatment for displaced scapula fractures in patients 65 and older is safe and can yield good functional results	IV
Operative vs. Non Op			
Jones and Sietsema (2011) [49]	Retrospective matched cohort	62 patients, 100% follow-up at a minimum of 12 months. Operative treatment in scapula fractures displaced more than 20mm results in similar healing, return to work, pain and complications as nonoperative fixation in less displaced fractures	III

of the following: (a) intra-articular gap/step off ≥3–10 mm, (b) displacement of the glenoid to the lateral border ≥10–25 mm, (c) glenopolar angle ≤20–22°, and (d) angulation ≥30–45° on scapula Y radiograph [11, 13, 22, 25, 34, 35].

From the case history, WT meets several of these indications, using even the most conservative measurements. There are two exit points on the lateral border, which can make the true degree of displacement difficult to appreciate. By "reducing" the segmental lateral border fragment, as shown in Fig. 5.6, displacement is measured at 25 mm. The glenopolar angle of WT equaled 20°. As described in the literature, patients with a GPA of <20° suffered from severe glenoid rotational malalignment and had worse long-term outcomes when treated conservatively [22, 25, 33]. Compounding this with the knowledge that WT is young and will certainly demand overhead

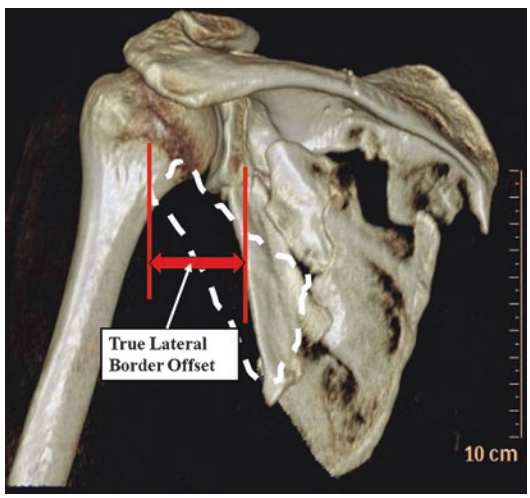

Fig. 5.6 3D CT reconstruction of the scapula with an illustration demonstrates alignment of the lateral border and the true lateral border offset

function post-injury, he is a good candidate for open reduction and internal fixation of the scapula.

Postoperatively, because the scapula is now surgically stabilized, the physician must direct the effort at regaining motion. This should be the primary goal for the first 4 weeks. Immediate active and passive range of motion is instituted. It is the authors' preference to use an indwelling interscalene catheter for the first 48–72 h to promote early gains in motion. Also, the use of pulleys and push–pull sticks used in the opposite extremity is a great resource and aids in rehabilitating upper extremity range of motion. Strength training is typically initiated at 4 weeks, beginning with light (3–5 lb) weights.

Follow-up for the surgically treated patient should be at 2, 6, and 12 weeks with routine radiographic imaging (AP, scapula Y, axillary). At 6 months and beyond, standard AP radiographs should be sufficient and likely are not even necessary unless untoward events mandate radiographs.

Predicting Long-Term Outcomes

Prior literature has suggested the benefits of operative treatment. Ada and Miller recommended ORIF for displaced scapula fractures after following eight patients treated operatively, with all reporting good clinical results and no residual pain at an average of 15 months post surgery [13]. Fifty percent of this same cohort with comminuted scapula spine fractures treated nonoperatively had residual pain. More recent publications have continued to show promising results. In a systematic review of 163 cases, 83% of the patients achieved excellent or good results after operative treatment of scapula fractures [6]. Outcomes of the analysis showed 70% of patients can expect good pain relief and 143° of abduction at an average of 53 months follow-up. The most common complication in this analysis was infection (4.2%) followed by nerve injuries (2.4%). The authors noted though that it was difficult to distinguish iatrogenic nerve injuries versus injuries accumulated at the time of trauma. Hardware removal, including clavicle plates, occurred in 7.1% of the patients due to local discomfort or mechanical failure [6]. Limitations on the time from injury to surgery continue to increase with satisfactory results; however, the surgery becomes more technically demanding [50]. Prospective studies with longer-term follow-up after operative management may be lacking, but the studies reviewed lead us to believe that WT will benefit from operative treatment and have a good result.

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6 Clavicle Fractures

Brian L. Seeto and Michael David McKee

SW: A 45-Year-Old Male with Shoulder Pain

Case Presentation

SW is a 45-year-old male mechanic who presents to the emergency department via EMS complaining of severe shoulder pain after a motocross accident. He denies any loss of consciousness. On primary survey, he demonstrates a GCS of 15, a patent airway, and is hemodynamically stable. He has severe pain on palpation of his left shoulder, but secondary survey is otherwise negative. His past medical history is unremarkable. He takes no medications and has no allergies. He smokes five cigarettes per day.

On examination of his left shoulder, he has ecchymosis, extreme tenderness with palpation of the clavicle, and pain on passive range of motion of the shoulder. Sensation over the anterior aspect of the deltoid is intact. He has a strong radial pulse in the left upper extremity and 5/5 strength throughout the left arm. He has normal capillary refill and sensation in his hand and a full painless range of motion about the left wrist and elbow. Radiographs of the left clavicle are demonstrated in Fig. 6.1.

B. L. Seeto
The CORE Institute,
Phoenix, AZ, USA

M. D. McKee (✉)
Department of Orthopaedic Surgery, University of Arizona College of Medicine - Phoenix,
Phoenix, AZ, USA
e-mail: mckeem@smh.ca

Interpretation of Clinical Presentation

A healthy active 45-year-old male (SW) presents with severe left shoulder pain after a motocross accident. The physical exam suggests a closed, isolated injury to the left shoulder girdle. Differential diagnosis at this stage includes fractures of the clavicle, scapula, proximal humerus, and/or rib; ligamentous injury of the glenohumeral, sternoclavicular (SC), and/or acromioclavicular (AC) joints; and dislocation of the glenohumeral, SC, and/or AC joints. The radiographs confirm the diagnosis of a midshaft, or middle-third, clavicle fracture with complete displacement and approximately 2 cm of axial shortening and comminution.

Clavicle fractures are common with an estimated incidence of 2–5% of all fractures. In a review of 690 clavicle fractures, 82% involved the middle-third segment of bone [1]. Patients presenting with a fractured clavicle are typically male (2:1 male to female), between the age of 10 and 40, and injured in a road traffic accident, fall from height, or sporting activity, especially cycling [2].

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Fig. 6.1 AP clavicle radiographs revealing a left displaced, comminuted, diaphyseal clavicle fracture

SW presents with no obvious life- or limb-threatening injuries. However, the initial evaluation of any trauma patient necessitates a thorough assessment and reassessment of their condition. Due to the proximity of the clavicle to the subclavian vessels and brachial plexus, a detailed neurological (sensory, motor, and reflexes) and vascular (pulses, temperature, and capillary refill) examination is important in the physical examination.

The injured area is carefully inspected focusing on the presence of swelling, deformity, tenting of the skin, or any open wounds that may indicate an open or impending-open fracture. A note should be made of any previous scars or old incisions. Clavicle fractures are occasionally missed in the multiply injured or obtunded trauma population, and care should be taken to evaluate each patient thoroughly. In a recent study of 692 patients admitted to a Level I trauma center over 13 months, 17 (2.5%) had missed injuries of which 2 were clavicle fractures [3]. Open midshaft clavicle fractures, while rare and often from high-energy mechanisms of injury, have a strong correlation with serious injuries involving the head, chest, spine, and upper extremity [4, 5]. In a study by Taitsman and associates, 1740 (2.6%) of the 67,679 trauma admissions over a 13-year period had clavicle fractures, with only 24/1740 (1.4%) being open fractures [5].

A complete examination of the shoulder girdle and neck should be carried out and documented. Care should be taken to protect the cervical spine. Spine precautions can be discontinued only after clearance by the standard trauma protocol. It is important to document whether the glenohumeral joint is reduced and if the axillary nerve is functioning. The length of the injured clavicle is measured from the SC joint to the AC joint and compared with the opposite side. Any amount of shortening should be evaluated both clinically and radiographically.

Figure 6.1 illustrates a typical appearance of a midshaft clavicle fracture with an oblique orientation, shortening, and Z-shaped deformity. Dedicated clavicle radiographs are important in the characterization and classification of clavicle fractures [6]. Standard radiographs include anteroposterior (AP) and 15–30° AP cephalic tilt Zanca views. An estimated length of displacement is quantified on calibrated, standardized radiographs, recognizing the limitations of this technique [7].

The direction of fracture displacement normally occurs in the coronal plane, due in part to the pull of the sternocleidomastoid muscle tilting the medial clavicular fragment superiorly and posteriorly, while gravity and the pull of the pectoralis major muscle on the humerus displace and rotate the lateral fragment inferiorly and anteriorly. In lateral-third fractures, the attachments of the conoid and trapezoid coracoclavicular ligaments may avulse a segment of the bone from the inferolateral aspect sometimes referred to as a conoid process or tubercle avulsion fracture. In Fig. 6.1, the conoid and trapezoid ligaments are most likely intact and attached to the distal-third fragment, as the coracoclavicular space appears normal. The sternoclavicular and acromioclavicular joints are aligned.

Initial treatment of patient SW should include a broad arm sling for comfort to his injured left upper extremity. However, the definitive management of a closed, displaced clavicle fracture in a young, healthy, active individual such as

SW remains controversial as our understanding of the natural history of these fractures continues to evolve [8, 9]. Several nonoperative and operative techniques have been compared to one another without a clear indication of which patient subgroups would benefit from operative treatment [10–19].

Declaration of Specific Diagnosis

SW is a 45-year-old healthy male presenting with a closed, displaced, comminuted, midshaft fracture of the left clavicle.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Rapid return to function and/or work
2. Union of fracture
3. Recovery of strength and range of motion of shoulder
4. Minimize the risk of complications (nonunion and symptomatic malunion)

Treatment options include:
Conservative/nonoperative treatment

1. Sling for comfort, early motion
2. Figure-of-eight bandage (or splint), early motion

Surgical treatment

1. Plate fixation
2. Intramedullary (IM) fixation

Evaluation of the Literature

To identify publications relating to the treatment of midshaft clavicle fractures, PubMed (http://pubmed.gov/, U.S. National Library of Medicine, (NLM®)) was searched. Using the Medical Subject Heading (MeSH) database search function, the major headings "Fractures," "Bone," and "Clavicle" were added to the search builder. The keywords "midshaft" or "middle" were added to the search: ("Clavicle"[MeSH]) and ("Fractures, Bone"[MeSH]) and ("midshaft" or "mid-shaft" or "middle"). Next, the search was limited to include articles published from 1975 to 2017, in the English language, and involving adult subjects aged 19–44 (adult). This search yielded 526 results. All 526 titles and/or abstracts were reviewed, and from this list 59 abstracts were reviewed in detail. An additional limit of "clinical trial" yielded 59 articles of which 11 were selected as high-quality studies relating to the treatment of displaced, midshaft clavicle fractures in adults [13, 14, 16–24].

Detailed Review of Pertinent Articles

Diaphyseal clavicle fractures have traditionally been treated nonoperatively and were considered to be benign injuries with little long-term functional impairment [11, 25]. However, a number of recent clinical trials, described below, have evaluated both conservative and operative treatment strategies for patients with displaced clavicle fractures, and we are left with many questions as to what is the best treatment option in the adult population [26–29].

The following section focuses on the best evidence to guide treatment decisions for our patient, SW.

Conservative/Nonoperative Management

For hundreds of years, variations of slings and bandages were applied to the upper extremity in an attempt to obtain and maintain a closed reduction of midshaft clavicle fractures. Currently, the two most common nonoperative treatment protocols recommend a simple, Velpeau-style, broad-arm sling and a figure-of-eight bandage for comfort with an early range of motion protocol [11, 27, 30].

Andersen and associates conducted a randomized, clinical trial with 61 patients comparing a sling and figure-of-eight bandage in two treatment groups [11]. The authors found the simple sling to be better tolerated, with potentially fewer complications than the figure-of-eight bandage. There were no differences in the functional, radiographic, and cosmetic results between the two groups. Similarly, a randomized, controlled study performed by Ersen and associates demonstrated that a figure-of-eight bandage had a higher mean visual analog scale pain score on the first day when compared to a broad arm sling while providing no difference in the mean shortening of fracture [25]. A second retrospective cohort study of 136 patients had similar findings of no difference in radiographic clavicle shortening or clinical outcomes using a Constant–Murley score between a sling and figure-of-eight bandage [27]. There is no evidence that a closed reduction maneuver can maintain the alignment of displaced clavicle fractures for any significant period of time.

Nonoperative management of clavicle fractures avoids potential surgical complications of infection, hardware prominence or failure, refracture after hardware removal, hypertrophic or dysesthetic scars, and the need for reoperation. There are also case reports of the uncommon but serious risk of intraoperative neurovascular injury [31].

Historically most clavicle fractures have been treated nonoperatively. This is in part due to two influential articles from the 1960s. Neer [26] and Rowe [1] reported a nonunion rate of 0.1% in 2235 patients and 0.8% in 690 patients, respectively, with midshaft clavicle fractures treated with closed reduction. Critics of these studies suggest that a large number of adolescents were included – a population in which fractures generally heal without sequelae [32]. Additionally, these studies had significant numbers of patients lost to follow-up, and assessments at the final visits were not rigorous [1, 26]. Recent literature has highlighted the risks of nonoperative treatment of displaced midshaft fractures of the clavicle, including the possibility of developing a symptomatic malunion and an increased risk of nonunion [9, 14].

Complications associated with malunion of the clavicle can include musculoskeletal pain related to muscle weakness and shoulder impingement, malalignment or winging of the scapula (which displaces with the distal fragment), cosmetic concerns such as a drooping shoulder and a “bump” deformity, and, less commonly, neurologic symptoms from brachial plexus irritation. In 1997, Hill and colleagues found that patients with displaced fractures with greater than 2 cm of initial shortening had a higher risk of nonunion and decreased patient satisfaction when treated nonoperatively [9]. In this consecutive case series of 242 clavicle fractures, 52 patients with middle-third fractures were reviewed. Sixteen patients (31%) were dissatisfied with their clinical outcome following nonoperative management.

A prospective long-term follow-up study by Nowak and colleagues found that 96 of 208 patients (46%) treated nonoperatively did not feel fully recovered at their 9- to 10-year follow-up [33]. Results correlated comminution and displacement with pain and poor satisfaction on patient survey. Additionally, 27% of patients were unhappy with the appearance of their shoulder.

Lazarides and colleagues conducted a retrospective study from 1998 to 2001 reviewing 272 patients with clavicle fractures treated nonoperatively [34]. They found that 34 patients (25.8%) were dissatisfied with the results of their nonoperative management. Initial shortening of the clavicle greater than 1.8 cm in males and 1.4 cm in females was significantly associated with poor satisfaction on patient survey.

Our patient, SW, is an active, healthy adult presenting with a shortened (approx. 2 cm) and displaced midshaft clavicle fracture. The goals of treatment are to achieve rapid return to function, early union, and recovery of strength and range of motion while minimizing the risk of complications. Nonoperative management may delay SW’s return to activity and is associated with a risk of a higher rate of nonunion, malunion, patient dissatisfaction, and worse functional outcome scores. Careful consideration of the patient's occupation, in this case, a mechanic, is also critical. If he were to select nonoperative management, he could expect some degree of radiographic malalignment, with or without symptoms; asymmetric appearance of the right shoulder, due to shortening and depression of shoulder girdle; and an increased likelihood of delayed union or nonunion in the range of 15–20% [8, 9, 14].

Operative Management: Plate Fixation

The use of plate osteosynthesis to treat midshaft clavicle fractures has increased in popularity for completely displaced fractures with greater than 2 cm of shortening in young, active adults. However, the only absolute indications for open reduction and internal fixation are in cases of open fractures and fractures with associated upper extremity neurovascular compromise. The remaining relative indications include fractures with tenting of the skin and those with associated scapulothoracic dissociation or displaced glenoid fractures. Other relative indications include the need for quicker return to activity (faster healing) and prevention of secondary symptomatic malunions [14, 21, 34].

Recent studies with long-term follow-up and patient-oriented outcome measures have estimated the incidence of nonunion and symptomatic malunion in displaced midshaft clavicle fractures to be approximately 15–20% [8, 9, 14, 15]. Hill and colleagues found a nonunion rate of 15% in fractures managed nonoperatively, 2% in those managed with plate fixation, and 2.2% for those managed with IM pinning [9]. Zlowodzki and colleagues completed a systematic review of the English literature identifying 22 studies and 2144 patients [15]. The nonunion rate for nonoperative treatment was 5.9% for all midshaft clavicle fractures and 15.1% for displaced midshaft fractures. They identified the following risk factors associated with nonunion after nonoperative treatment of clavicle fractures: fracture displacement (relative risk = 2.3), fracture comminution (relative risk = 1.4), female gender (relative risk = 1.4), and advancing age.

The 2007 Canadian Orthopaedic Trauma Society (COTS) trial compared nonoperative treatment to open reduction internal fixation with a plate [14]. 132 patients were randomized to standard sling (65) or small fragment plate (67). They found improved CS and DASH scores in the operative fixation group at all time points up until 52 weeks follow-up ($P = 0.001$ and $P < 0.01$, respectively). Time to fracture union was 16.4 weeks in the operative group and 28.4 weeks in the nonoperative group ($P = 0.001$). There were seven nonunions in the nonoperative group and two nonunions in the operative group ($P = 0.042$). Symptomatic malunions requiring further treatment were present in 9 of 49 patients (18.3%) treated nonoperatively at 1 year of follow-up, but none were present in the operative group ($P = 0.001$).

The overall complication rate for the operative group was 17.7% versus 32.6% complication rate for the nonoperative group (nonunions and symptomatic malunions). Complications unique to the operative group included infection (three cases) and the need for hardware removal due to prominent implants (five cases). There were no major neurovascular complications reported. This trial provides Level I evidence regarding the overall improved outcomes that can be achieved in select patients (active, healthy individuals between 16 and 60 years of age) with completely displaced (mean displacement of 2 cm) midshaft clavicle fractures [14].

Another study by Mirzatolooei compared nonoperative treatment (24) to open reduction internal fixation with a plate (26) in a randomized clinical trial of 60 patients [24]. One patient in each group had a nonunion, and rates of malunion were significantly lower in the operative group (4 or 15.4%) than the nonoperative group (19 or 79.2%). The nonunion in the operative group occurred secondary to infection. This study reported significantly better DASH and CS scores in the operative fixation group at 12 months, with lower rates of pain, weakness, and limitation of motion.

In 2012, Virtanen and colleagues randomized 60 patients to either sling immobilization or plate osteosynthesis. At 1-year follow-up, the nonoperative group had a higher nonunion rate (24% vs. 0%) however similar Constant, DASH, and pain scores compared to the operative group [16]. A study published in 2013 by Robinson and coworkers also demonstrated the significant reduction in the nonunion rate when midshaft clavicle fractures were treated operatively. Overall, DASH and Constant scores were significantly better following open reduction and plate fixation than after nonoperative treatment at 1-year follow-up. However, when patients with nonunion were excluded, there were no significant differences between the operative and nonoperative groups. Patients who had undergone operative fixation were less dissatisfied with symptoms of shoulder droop, local bump at the fracture site, and shoulder asymmetry, albeit with an increased cost of treatment [17].

Van der Ven Denise and coworkers in 2015 demonstrated a significantly higher rate of complications in patients who had undergone operative therapy (31% vs. 9%) while providing no difference in functional outcome between plate fixation and conservative treatment at 5-year follow-up [18]. A recent meta-analysis published by Bhandari and coworkers could not support the routine use of internal fixation for the treatment of displaced midshaft clavicle fractures, with minimal differences in the clinical outcomes at 1 year. The authors found that complication rates were high regardless of the treatment approach [19].

The individual characteristics of the patient or fracture that will benefit from operative treatment have not been clearly defined. The COTS trial showed that 33 of 49 patients (67.4%) with 100% displaced clavicle fractures treated nonoperatively healed with results essentially the same as the operative group [11]. Possible predictors of poor outcome based on current literature include marked displacement and/or shortening at the fracture site (with a droopy or "ptotic" shoulder), fracture comminution, female gender, and advanced age. In the case of SW, he has two of four risk factors for a worse outcome with nonoperative management.

Several biomechanical and clinical papers have focused on the type of plate (reconstruction versus 3.5 mm small fragment plate) and anatomic location of fixation (anterior or superior) for midshaft clavicle fractures with and without comminution. In a study by Drosdewech and coworkers, the biomechanics of anterior and superior locations of plate fixation were compared to IM fixation in 20 cadaveric midshaft clavicle fractures [35]. More rigid plates (dynamic compression plates (DCP) and locked compression plates (LCP)) placed on the superior clavicle for simulated unstable midshaft clavicular fractures resisted higher bending and torque loads than did less rigid reconstruction plates or IM devices. A cadaveric study by Harnroongroj and coworkers concluded that stability against a bending moment was improved, with superior plating in fractures without an inferior cortical defect and anterior plating in fractures with an inferior cortical defect [36].

In 2006, Collinge and colleagues looked at a consecutive clinical series of 80 patients with midshaft clavicle fractures treated with anterior-inferior plate fixation [37]. Patients were evaluated with both clinical and radiographic examinations, the American Shoulder and Elbow Surgeons Shoulder Assessment, and the Short Form-36 outcomes questionnaire. At 2 years follow-up, they had similar complication rates related to failure of fixation, infection, and nonunion but concluded that anterior-inferior plating has the potential advantage of avoiding infraclavicular neurovascular structures. Similar findings were made in the 2015 study of Sohn and associates which compared the clinical outcomes of midshaft clavicle fractures treated with a 3.5 mm locking reconstruction plate with either superior or anteroinferior plating with an average follow-up of 18 months. The authors concluded that the two plating techniques showed no difference in regard to complications or functional outcome scores [38].

Other studies have evaluated the biomechanics of precontoured plates compared to standard plates and have shown no difference [39]. Vanbeek and colleagues retrospectively reviewed 52 displaced midshaft clavicle fractures treated with plate fixation and found lower rates of prominent hardware in those treated with precontoured plates (9/28 patients) than those treated with noncontoured plates (9/14) [40]. The percentage of patients who underwent hardware removal was less in the precontoured group (3/28) than the noncontoured group (3/14). In 2016, Rongguang and associates published a series of 130 patients comparing precontoured and noncontoured plates. They found similar DASH and Constant scores at final follow-up (mean 20 months). There were three postoperative complications in the precontoured group (69) and six in the noncontoured group (61). The noncontoured plates had a significantly higher rate of hardware prominence (54% vs. 28%) and subsequent hardware removal (66% vs. 45%) [41].

Timing of surgery is also a consideration in the management of acute displaced midshaft clavicle fractures. Potter and colleagues compared objective outcomes in 15 patients who underwent delayed operative intervention for nonunion and malunion with 15 patients who had immediate open reduction and internal fixation [42]. The delayed group had a mean time from fracture to operative intervention of 63 months (range, 6–67 months). They found no difference in satisfaction with the procedure, shoulder strength, and DASH scores. The acute fixation group had significantly better Constant shoulder scores and endurance in forward flexion. This study suggests that the outcome after delayed reconstruction will on average be slightly inferior to what might have been obtained with acute fixation. A more recent study by Das and associates compared 68 patients who underwent acute fixation (<3 weeks) with 29 patients who underwent delayed fixation (3–12 weeks). They found no statistical difference in the mean quickDASH and Oxford Shoulder Score at a mean follow-up of 31 months. They advocated that patients undergoing delayed fixation, up to 12 weeks from the date of injury, do not experience a higher complication rate and equal functional outcome and quality of life scores despite a potentially more challenging operative procedure [43]. However, waiting 3–12 weeks before fixation negates one of the principal advantages of early intervention: a more rapid return to function.

For patient SW to decide on operative versus nonoperative management of his acute clavicle fracture, the potential benefits of operative fixation must be discussed in relation to risks of potential complications. Criticisms of initial operative management of clavicle fractures include the potential for a hypertrophic scar or regional dysesthesia from injury to the supraclavicular nerves. Also, there is the risk of infection, hardware prominence, and the required local soft tissue trauma required for exposure of the bone fragments [16, 20]. Potentially, some of these complications are avoidable with IM techniques, yet the superiority of IM fixation remains to be clinically proven [34].

Operative Management: Intramedullary Fixation

IM fixation is proposed to be a less invasive alternative to plate fixation for midshaft clavicle fractures [20]. The goal of IM fixation for displaced clavicle fractures is to maintain fracture reduction (length, angulation, and rotation) while reducing the amount of periosteal and soft tissue dissection from the bone. Additionally, the IM devices can be inserted under fluoroscopic guidance and may have the advantage of a smaller incision and scar. Many different variations on IM devices have been available for approximately 40 years. More recently, IM stabilization with titanium elastic nails has increased in popularity [37].

Six randomized trials were identified in the literature pertaining to IM fixation of displaced midshaft clavicle fractures [20–22, 44–47]. Smekal and associates reported on 60 patients randomized to sling (30 patients) or elastic titanium IM pin fixation (30 patients) and followed the groups until 2 years post-injury [44]. The operative group had a faster time to union, lower DASH, and higher CS scores. Delayed union was identified in 6 of 30 patients (20%) in the nonoperative group. In 2009, a prospective randomized study by Judd and colleagues of 57 patients (military personnel) randomized to IM fixation (29) or sling (28) found no significant difference between operative and nonoperative groups at 1 year [22]. The operative group did, however, demonstrate significantly higher single assessment numeric evaluation and L'Insalata scores at 3 weeks. The complication rate was greater in the operative group including nonunion, refracture, infection, and prominent hardware. Nearly half of the patients in the operative group lost some of the original reduction. Assobhi compared anteroinferior plating with retrograde titanium elastic nail fixation in 38 patients with a minimum of 12 months follow-up. In this study, the two fixation techniques had similar results in terms of radiological and functional outcomes following the 12th week. However, earlier union and functional recovery was obtained at the 6th week by the flexible nail group while also suffering a lower complication rate (15.8% vs. 0%, $p > 0.05$). In 2015, van der Meijden and associates [46] published the findings comparing 58 patients who received plate fixation with 62 patients who received intramedullary nail fixation with outcome measurements up to 1 year postoperatively. Similar to Assobhi, these authors concluded that similar results in terms of the DASH or Constant score were equal at 6 months postoperatively; however, the plate-fixation group suffered less disability prior to the 6-month mark. There was no difference in the rate of complications when comparing fixation techniques. A simultaneously published paper by Andrade-Silva and colleagues [47] revealed the same conclusion. At 6 or 12 months, there was no difference in the functional outcomes or rate of major complications when comparing plate or flexible IM nail fixation. The only significant differences were (1) plate fixation left more residual shortening and (2) the nail group was left with more implant-related pain.

If surgery is the treatment of choice for patient SW, the preferred surgical technique (IM or plate fixation) remains controversial. No single technique has become standard in the IM nailing of displaced midshaft clavicle fractures, and no definitive recommendations can be made. There appears to be a high rate of postoperative complications, with some studies reporting up to 50% complications including implant breakage, temporary brachial plexus palsy, skin breakdown over the pin, and implant protrusion from the lateral clavicle [48]. Like any other unlocked device, IM nails do not hold length or rotation well in comminuted fractures [22].

Evidentiary Table and Selection of Treatment Method

Table 6.1 summarizes important clinical trials relating to the treatment of displaced midshaft clavicle fractures [14, 16, 21, 24, 45–47]. Based on a review of the evidence, it is the authors' opinion that the best treatment for our 45-year-old, active, male patient, SW, is primary fixation with plate osteosynthesis using a strong, precontoured plate in the superior anatomic position with lag screw fixation.

The treatment goals for SW of rapid return to function (or work), early union of fracture, and recovery of strength and range of motion, with minimal complications, are best achieved with plate fixation. While IM fixation with an elastic stable IM nail may prove to have similar outcome results to plating with a more cosmetic result, the clinical evidence and biomechanical literature currently support plate fixation as a more predictable and superior outcome, especially in a North American population.

Definitive Treatment Plan

The surgical goal for managing a displaced midshaft clavicle fracture is to restore alignment of the shoulder girdle. This is achieved with anatomic reduction of the fracture with reconstitution of clavicular length and rotation. The time from injury to surgery, the amount of displacement and comminution, and the body habitus of the patient all contribute to the difficulty of the procedure. Severely comminuted midshaft clavicle fractures may require a bridge-plating technique rather than lag screws and compression plating. Radiographic comparison between injured and intact sides helps determine the amount of initial shortening and the reduction required intraoperatively.

Position the patient for the procedure in the beach chair position with a small bump under the posteromedial aspect of the injured shoulder. Prepare and drape the clavicle area in a sterile manner. If desired, the arm can be free draped to help achieve the reduction, although this is not typically required.

Table 6.1 Evidentiary table: A summary of the evidence for treatment of midshaft clavicle fractures in adults

Author (year)	Description	Summary of results	Level of evidence
Canadian orthopedic trauma association (COTS) (2007) [14]	Randomized clinical trial	132 patients randomized to sling (65) or plate fixation (67). The CS and DASH scores were significantly better at all time points for the operative group ($p < 0.01$). Nonunion and symptomatic malunion were higher in nonoperative group. 3 infections, 5 hardware removal surgeries in operative group	I
Smekal et al. (2009) [21]	Randomized clinical trial	68 patients randomized to sling or elastic titanium intramedullary (IM) pin fixation. 60 patients (30 in each group) were followed for 2 years post-injury. The operative group had faster time to union, lower DASH, and higher CS scores. Delayed union occurred in 6 of 30 patients in the nonoperative group	I
Mirzatolooei (2011) [24]	Randomized clinical trial	60 patients, randomized into open plate fixation (26) and nonoperative treatment (24) and followed for 12 months. 1 nonunion in each group. 4 malunions in the operative group and 19 malunions in the nonoperative group. 1 infection in the operative group. DASH and CS scores significantly better in the operative group	I
Virtanen (2012) [16]	Randomized clinical trial	60 patients, randomized to either nonoperative (32) or plate fixation (28) and followed for 12 months. No difference in the CS, DASH, or pain between the two groups at 1-year follow-up. All fractures healed in the operative group, but six nonunions occurred in the nonoperative group	I
Assobhi (2011) [45]	Randomized clinical trial	38 patients, equally randomized to plate fixation or retrograde titanium elastic nail fixation (RTEN) and followed for a minimum of 12 months. Higher CS in the RTEN group at 6 weeks but equal at subsequent evaluations. One nonunion, one infection, and one infection in the plate group. No complications in the RTEN group	I
Van der Meijden (2015) [46]	Randomized clinical trial	120 patients, randomized either to plate fixation (58) or intramedullary nailing (62) and followed for 12 months. No significant differences in the DASH or CS at 6 months postoperatively. The mean number of complications per patient, irrespective of their severity was similar between fixation techniques	I
Andrade-Silva (2015) [47]	Randomized clinical trial	59 patients, randomized to either plate fixation (33) or elastic stable intramedullary nailing (26) and followed for a minimum of 12 months. No difference in the 6- or 12-month DASH or CS. Residual shortening was 0.4 cm greater in the plate group ($p = 0.032$). Implant-related pain was more frequent in the nail group ($p = 0.035$)	I

CS Constant shoulder score, *DASH* disability of the arm, shoulder, and hand, *DCP* limited contact dynamic compression plate, *LCP* locking compression plate, *RECON* reconstruction plate, *SANE* single assessment numeric evaluation

Preoperatively mark bony landmarks to allow proper placement of the incision. Expose the clavicle through a 5–10 cm incision centered over the fracture site. With experience, a smaller incision can be used and is preferred. Identify and protect where possible visible branches of the supraclavicular nerves. Separate skin from the deep fascial layer to produce a "mobile window," and facilitate the operation. Dissect fascia and periosteum from the bone ends with care to preserve soft tissue to any comminuted fragments of the bone. A self-retainer is often useful to maintain visualization.

Expose and debride fractured bone ends to clear interposed hematoma and soft tissues. Use Kirschner wires and reduction clamps when possible to obtain provisional fixation while inserting the lag screw. Small butterfly fragments may also be lagged with a mini-fragment screw in order to simplify the fracture pattern. Careful

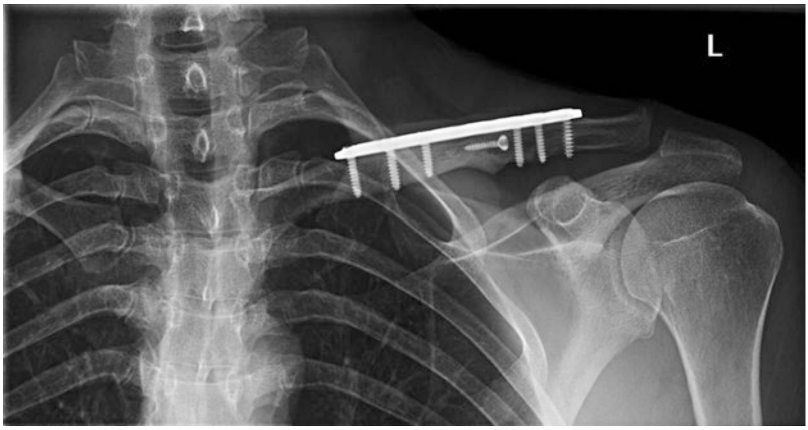

Fig. 6.2 AP clavicle radiograph demonstrating complete union of a multifragmentary, displaced, shortened midshaft clavicle fracture following open reduction internal fixation with a lag screw and superior plating

assessment of length and rotation is important in restoring normal clavicle anatomy. Place a strong, precontoured, low-profile clavicle-specific plate along the superior surface of the clavicle, and hold it in place with reduction clamps. A minimum of three screws and a lag screw or four screws on either side of the fracture is preferred while drilling, and using the depth gauge, care should be taken to not plunge into the infraclavicular neurovascular structures or pleural space.

Assess stability of the construct, and irrigate the wound with sterile saline solution. With the wound filled with saline wash, ask the anesthesia team to perform a Valsalva maneuver, thus increasing intrathoracic pressure and assessing pleural integrity prior to closure (bubbles from the wound bed may signify a pneumothorax). Two-layer closure over the superiorly positioned clavicle plate is critical. Close the deep fascia over the plate with interrupted or running absorbable sutures. Close the skin with a subcuticular closure, horizontal mattress sutures, or staples. Apply a nonadhesive dressing to the wound, and reinforce with a dry gauze dressing. Apply an arm sling for patient comfort. The postoperative protocol includes an upright clavicle radiograph to assess fixation. Perform a postoperative (maximal inspiration) chest radiograph and serial clinical examinations if a pneumothorax is suspected.

No evidence-based literature exists to guide acute postoperative management of clavicle fractures, and the following suggestions are based on the current standard of care. Start early gentle unrestricted range-of-motion exercises of the shoulder, usually at 1–2 weeks. Begin strength and resistance exercises at 6 weeks if the patient has a favorable clinical examination and the radiographs show evidence of healing. Return to sports is determined on a case-by-case basis but usually can begin by 8–12 weeks if the patient is asymptomatic and the fracture is clinically and radiographically healed. Patients who have difficulties complying with postoperative protocols may require prolonged immobilization and can have a delayed return to sports. Figure 6.2 demonstrates complete union of the previously displaced and shortened fracture following lag fixation and superior plating.

Predicting Long-Term Outcomes

Long-term studies of clinical outcomes after primary fixation of displaced midshaft clavicle fractures are limited in the literature. Schemitsch and colleagues [49] published a follow-up of the COTS study group comparing the clinical outcomes (DASH and CS scores) at 1 and 2 years post-injury and found a plateau effect with no significant change in scores after 1 year in either group. Additionally, the DASH and CS scores continued to be significantly better in the operative than the nonoperative cohorts at 2 years. The authors conclude that this plateau effect can be used to counsel patients. Following acute operative fixation of his displaced midshaft clavicle fracture, SW can expect to improve up to 1 year and then reach a steady state in terms of functional outcome.

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7 Proximal Humerus Fractures

Erik A. Lund and Paul S. Whiting

KN: A 67-Year-Old Female with Right Shoulder Pain

Case Presentation

KN is a 67-year-old female who presents to the emergency department via EMS complaining of severe right shoulder pain after a high-speed motor vehicle accident in which she was a restrained passenger. She denies any loss of consciousness. On primary survey, she demonstrates a GCS of 15 and a patent airway and is hemodynamically stable. On secondary survey, she demonstrates severe pain with passive range of motion of the right shoulder. There is no motor or sensory deficit, and the skin is intact at the right shoulder, without dimpling. The remaining physical exam and her past medical history are unremarkable.

Anteroposterior radiographs of the right shoulder and humerus are demonstrated in Fig. 7.1a, b.

E. A. Lund · P. S. Whiting (✉)
Department of Orthopedics and Rehabilitation, University of Wisconsin-Madison, University of Wisconsin Hospital and Clinics, Madison, WI, USA
e-mail: whiting@ortho.wisc.edu

Interpretation of Clinical Presentation

The patient presents with an isolated right proximal humerus fracture. This injury commonly occurs in the elderly from low-energy mechanisms, such as a fall from standing [1]. In 2016, a comprehensive national registry [2] demonstrated an incidence of 175 proximal humerus fractures per 100,000 person-years. Seventy-three percent of these fractures occurred in women, and the incidence increased by 35% over the 11-year period between 2001 and 2012. Open fractures are rare, but closed fractures can result in displacement sufficient to cause severe tenting, dimpling or pressure necrosis of the skin, necessitating an immediate attempt at closed reduction [3]. Vascular and neurologic injuries are also very uncommon. When nerve injuries do occur, the most common causes are traction injury to the axillary nerve or direct injury to the brachial plexus. Due to the high rate of spontaneous recovery, most clinicians simply observe these nerve injuries [4].

Although patient KN's injury occurred in a high-speed motor vehicle collision, the physical exam findings and fracture pattern are consistent with those commonly seen following a low-energy proximal humerus fracture. The radiographs demonstrate an impacted fracture of the surgical neck of the humerus with a minimally displaced fracture line extending between the

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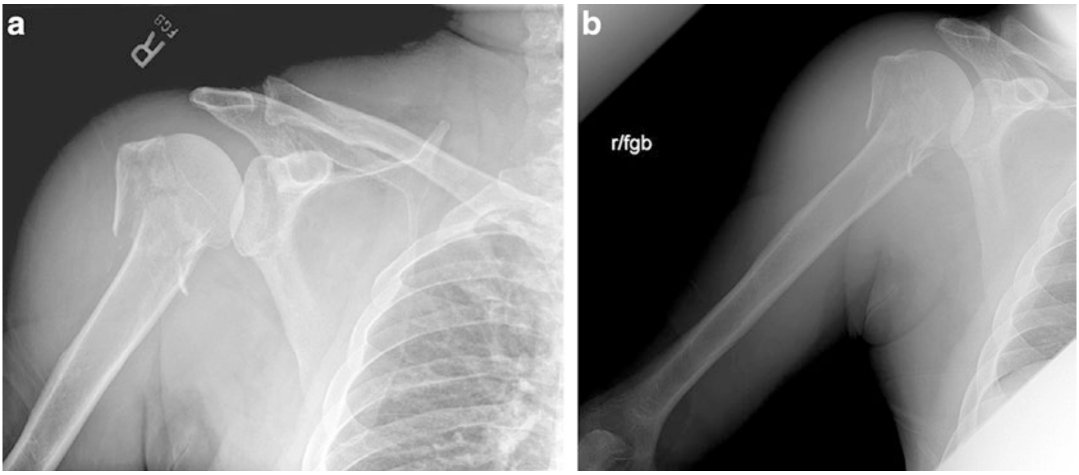

Fig. 7.1 AP radiographs of the right shoulder (**a**) and humerus (**b**)

greater tuberosity and the humeral head. There is valgus angulation of approximately 20°, with shortening of approximately 1.5 cm. Some orthopedic surgeons would refer to this fracture pattern as a Neer three-part fracture. However, according to Neer's original classification system, this fracture should be classified as a two-part surgical neck fracture; the minimally displaced greater tuberosity fracture does not "count" as a separate fragment [5].

Declaration of Specific Diagnosis

KN is a 67-year-old female who presents with a high-energy isolated right proximal humerus fracture, specifically a Neer two-part surgical neck fracture, with a minimally displaced greater tuberosity fracture.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Stabilize the proximal humerus fracture.
2. Maximize shoulder range of motion.
3. Maintain muscle strength.
4. Minimize shoulder pain.
5. Return to normal activities and previous level of function.

Treatment options include the following:
Conservative/nonoperative treatment

1. Sling with early or delayed physical therapy and range of motion exercises.

Surgical treatment

1. Closed reduction and percutaneous fixation
2. External fixation
3. Open reduction and internal fixation
   (a) Tension band fixation
   (b) Plate fixation
      (i) Standard (non-locking)
      (ii) Locking
4. Antegrade intramedullary nail fixation
5. Arthroplasty
   (a) Hemiarthroplasty
   (b) Reverse total shoulder arthroplasty

Evaluation of the Literature

To identify publications pertaining to the treatment of proximal humerus fractures, we completed a comprehensive search of Medline and PubMed. Keywords searched included proximal *and* (humerus *or* humeral) *and* (fracture *or* fractures), and MeSH indexing was also utilized. We identified 3014 articles. After title and abstract review, we reviewed the 119 most relevant manuscripts, taking into consideration level of evidence, methodologic quality, reporting treatment methods, and outcomes. We excluded studies involving pediatric patients, other species, and fractures of the humeral shaft or distal humerus. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

For decades, researchers have investigated several surgical treatment options for proximal humerus fractures. As more randomized control trials (RCTs) are published each year, the quality of the available literature improves. Yet, as we discuss in detail below, no single surgical technique has consistently demonstrated superior outcomes when compared with other techniques or nonoperative treatment.

The following review recognizes the controversy associated with the treatment of proximal humerus fractures and evaluates the current literature to determine the most appropriate management for our patient, KN. Our review is divided into two main parts. In the first part, we present data summarizing the outcomes and complications of the various treatment techniques. In the second part, we review the literature comparing treatment methods to one another, focusing on RCTs and other high-quality prospective studies.

Part 1: Outcomes of Individual Treatment Methods

Nonoperative Treatment

Before intervening for a given injury or condition, the physician must understand the natural history. Prior to significant advancements in orthopedic surgery and the advent of plate osteosynthesis, fractures of the upper extremity were treated with immobilization and activity restriction. For much of the twentieth century, nonoperative treatment served as the mainstay of treatment for the vast majority proximal humerus fractures, especially those that were minimally displaced. Early data from the Scandinavian literature confirmed that patients faired well with nonoperative care. Lundberg and Bertroft each published RCTs in 1979 [6] and 1984 [7], respectively, comparing different methods of therapy for treatment of proximal humerus fractures. Both authors found that independent home therapy produced results equivalent to supervised physical therapy. These studies also identified a projected timeline for recovery and reported that patients exhibited the most improvement during post-injury weeks 3–8. More recent nonoperative RCTs have also focused on rehabilitation protocols. In 2003, Hodgson and colleagues [8] randomized 86 patients into immediate vs. delayed physiotherapy after 3 weeks in a cuff-and-collar sling. At 16 weeks, the immediate therapy group had less pain and improved function. At 1 year, this benefit lost statistical significance. Soon after, in 2007, another RCT [9] reported a benefit to early mobilization compared to using a sling for the first 3 weeks after injury. A forthcoming RCT [10] has been designed to compare the efficacy of in-home tele-rehab vs. in-person home therapy. A pilot study in 2014 using the same tele-rehab protocol reported an 82% patient satisfaction rate [11].

Since a significant portion of patients with proximal humerus fractures have osteopenia or osteoporosis, Doetsch and colleagues conducted an RCT [12] in 2004 to determine the impact of calcium and vitamin D supplementation on bone mineral density (BMD) at the fracture site. 37% of patients had low serum vitamin D and calcium levels on presentation, but BMD increased at the fracture site in the vitamin D and calcium cohort compared with placebo after just 6 weeks.

Several prospective and retrospective observational studies have demonstrated good overall functional outcomes and radiographic union with nonoperative treatment. In 1997, Koval and colleagues [13] evaluated 104 patients with an average age of 63 treated with standardized therapy for stable “1-part” fractures (<1 cm displacement, <45° angulation, and no gross motion between fragments). All fractures united within 12 months, and functional outcomes included 77% good-excellent, 13% fair, and 10% poor (half of whom had sustained a reinjury). Pain was absent or mild in 90% at the latest follow-up. Similar results were published by Keser and colleagues [14] in a 2004 series of 27 patients with minimally displaced fractures. By the 1-year mark, all fractures had healed, and the mean Constant score was 81. However, peak abduction torque remained decreased from the contralateral side in all but one patient. In 2008, Tejwani and coworkers [15] published a prospective study of 67 patients with Neer one-part fractures managed with a standardized rehabilitation program. Among the 84% of patients who completed 1-year follow-up, all fractures healed, there were no cases of osteonecrosis, and quality of life (as determined by SF-36 scores) was not significantly different from baseline preinjury status. Internal rotation and forward flexion were similar to the uninjured shoulder, and the average American Shoulder and Elbow Surgeons (ASES) score was 93.7 points, which was also not significantly different from baseline. Bahrs and coworkers [16] published a prospective cohort study in 2010 of 66 minimally displaced proximal humerus fractures, all of which healed with a median Constant score of 89 points at 1 year. The authors identified associations between final Constant score and age > 60, American Society of Anesthesiologists (ASA) score, and initial fracture displacement. Court-Brown and coworkers [17] had previously documented an association between age and functional outcomes in a 2001 study of 131 two-part surgical neck fractures. Patients under 50 years of age had an average Neer score of 92 at 1 year, while patients over 80 had an average score of only 72.

Valgus-impacted proximal humerus fractures represent the most common fracture pattern affecting elderly patients. In 2002, Court-Brown and coworkers [18] reported the functional outcomes of valgus-impacted fractures in 125 patients with a mean age of 71. According to Neer's criteria, 81% of patients achieved good to excellent results, and patients subjectively rated their functional results even more favorably. Interestingly, Constant scores were nearly identical between patients with minimally displaced fractures (mean score 74) and those with displacement of the greater tuberosity or surgical neck (mean scores of 73 and 72, respectively). However, fractures with displacement of both the surgical neck and greater tuberosity demonstrated a small but significant decline in function (mean score 67). While pain perception was equal among fracture types, the principal limitation in function was related to a loss in flexion and abduction power.

In 2009, Hanson and associates [19] prospectively enrolled a cohort of 160 patients consisting of 75 one-part fractures, 60 two-part fractures, 23 three-part fractures, and 2 four-part or head-splitting fractures. All fractures were initially treated nonoperatively, and 124 patients (87%) completed 1-year follow-up. Overall, nine patients (7.3%) required surgery – four due to significant fracture displacement and five due to subacromial impingement. At final follow-up, injured shoulders had an average Constant score 8.2 points lower and an average DASH score 10.2 points worse than the uninjured shoulder. No differences were found between fracture types, and the greatest variability in outcomes was found among the two-part fracture group.

In a 2011 prospective study, Foruria and associates [20] studied the impact of CT-determined fracture configuration on clinical outcome at 1 year in 93 patients. All but two patients healed, 73% achieved excellent or satisfactory results (Neer's criteria), and the rate of osteonecrosis (ON) was 6.5%. Those with valgus impaction and a greater tuberosity fragment (similar to our patient KN) and those with varus impaction had the highest visual analog scale (VAS) pain scores and greatest loss of function on both the DASH and ASES scales. While these results seem to contradict the previous findings by Jakob and associates [21] and Court-Brown and colleagues (which documented favorable outcomes in valgus-impacted fractures), Foruria and colleagues used a detailed fracture analysis and utilized validated outcome measures, thereby establishing a new standard by which to analyze functional outcomes following proximal humerus fractures.

Foruria and colleagues utilized the same CT-based fracture analysis to prospectively document radiographic findings at 1 year in their 2015 study of 89 fractures [22]. Varus fractures (with posteromedial comminution) healed with an average of 9° of varus angulation, 7° of retroversion, and 3.2 mm of shortening posteriorly. Valgus-impacted fractures tended to heal with less valgus deformity and less retroversion than noted on the injury films. Interestingly, only 20% of greater tuberosity fragments went on to displace more than 5 mm. The authors reported a 7% rate of ON, but five of the six cases involved only part of the humeral head, and these patients exhibited minimal symptoms.

In 2016, Bouchet and colleagues [23] reported the functional outcomes following nonoperative care of four-part fractures. There were no significant differences in Constant scores (88 vs. 86) or active forward flexion (133° vs. 139°) between the prospective ($n = 37$) and retrospective ($n = 21$) groups. The authors also identified the following risk factors that correlated with "failure" (defined by a weighted Constant score < 70): diabetes, alcoholism, and concurrent upper or lower extremity fracture. In 88% of the presenting cases, nonoperative treatment was recommended.

Based on these studies, consisting of mostly Level III and Level IV evidence, if patient KN elects for nonoperative management of her fracture, treatment with a sling and early physical therapy is likely to result in a healed fracture with a very low likelihood of nonunion or osteonecrosis. She may experience a small but appreciable loss of external rotation [15] and abduction strength [14, 17] when compared to the uninjured shoulder. Finally, Constant and ASES scores, while influenced mostly by age [15, 17], are unlikely to be significantly different than baseline values after 1 year.

Surgical Treatment

A variety of surgical treatment options exist for proximal humerus fractures, all of which fit into one of two main categories. Joint-preserving procedures include closed reduction with percutaneous pinning (CRPP), external fixation (ex-fix), tension band wiring, intramedullary nailing, and open reduction with internal fixation (ORIF), including minimally invasive plate osteosynthesis (MIPO). Joint-replacing procedures include hemiarthroplasty (HA), total shoulder arthroplasty (TSA), and reverse total shoulder arthroplasty (RSA). Multiple factors are considered when selecting the most appropriate procedure for a given patient. A 2016 publication using Swedish national registry data [2] of 98,770 proximal humerus fractures treated between 2001 and 2012 identified a significant increase in the proportion of fractures treated operatively over that time period (12.1% in 2001 to 16.8% in 2012). Among those treated operatively, ORIF was performed in 30%, followed by arthroplasty in 23% and IMN in 20%. The indications for surgery varied widely. Absolute indications included open fractures and irreducible fracture dislocations. However, indications for the majority of the fractures treated operatively were relative, including displacement, humeral head articular involvement, greater tuberosity fragment displacement, and fractures having >2 parts, nonunion, or malunion. Before proceeding with any particular surgical technique, the surgeon must be aware of the benefits as well as the associated complications and expected functional outcomes of that technique chosen. Additionally, surgical treatment should result in improvement in outcome (compared to nonoperative treatment) sufficient to warrant the risk of surgical complications. Below we present an analysis of the different surgical treatment options. Part 2 contains a comparative assessment of outcomes and complication rates between treatment options.

Closed Reduction and Percutaneous Fixation

Concerns about bone fragment viability in multipart fractures due to extensive soft tissue dissection with open techniques led to the development of less invasive techniques such as CRPP, external fixation, and MIPO. Several retrospective case series demonstrate good results in patients with minimally displaced two- or three-part fractures treated with percutaneous techniques, whether using screws, wires, or hybrid techniques. Less reliable results are described when this technique is used in displaced or four-part fractures.

In 1997, Resch and colleagues [24] reported on 27 patients treated with CRPP, including 9 three-part and 18 four-part fractures (13 valgus type). At 2 years, the three-part cohort reported good to very good function, with an average Constant score of 91 adjusted for age and gender, with no cases of avascular necrosis. In a subsequent 2011 study [25], Bogner and Resch evaluated 76 patients at least 70 years of age with displaced three- or four-part fractures treated with CRPP and a proximal humerus-specific external fixator. Fifty patients completed 34-month average follow-up with a 90% rate of fracture union. Mean Constant scores, reported as a percentage of the uninjured shoulder's Constant score, were 85% for three-part fractures and 69% for four-part fractures. Five patients (10%) experienced fragment displacement or K-wire migration, and four patients (8%) developed AVN, three of whom were revised to arthroplasty.

Three years later, Herscovici and colleagues [26] reported higher failure rates with smooth Kirschner wires compared to terminally threaded K-wires. Complications of treatment with smooth wires included collapse of the humeral head as well as K-wire loosening or migration. For these reasons, the authors recommended using terminally threaded wires, restoring the medial calcar and reducing the tuberosities accurately, and maintaining close follow-up to identify potentially serious complications associated with K-wire migration.

Calvo and coworkers [27] in 2007 reported the results of 50 patients treated with large diameter Kirschner wire CRPP. There were 27 surgical neck two-part, 17 three-part, and 6 four-part or head-splitting fractures. Reductions were good or fair in 92%, poor in 2%, and failed in 6%, requiring an alternative procedure. At mean 1-year follow-up, Constant scores averaged 82%, 89%, and 68% of the uninjured contralateral shoulder for two-, three-, and four-part fractures, respectively. Complications included wire migration in 36%, loss of reduction in 10%, AVN in 8%, superficial pin tract infections in 4%, and nonunion in 2% of patients. Fracture type correlated with quality of reduction and residual deformity, with four-part fractures having the worst reduction quality and deformity at final follow-up.

In a prospective multicenter study in 2007, Keener and coworkers [28] reported on 27 patients with displaced proximal humerus fractures that underwent CRPP with minimum 1-year follow-up. Mean age was 60 years, and fractures were classified as two-part in 26% of the cohort, three-part in 30%, and four-part in 44%. Final VAS pain scores were 0.9, 1.5, and 1.8 for each fracture pattern, respectively. For two-, three-, and four-part fractures, 1-year ASES scores were 88, 85, and 80, and Constant scores were 79, 79, and 67, respectively. All fractures healed, and one four-part valgus-impacted fracture developed AVN with severe pain. Complications included one case of early pin loosening, one varus malunion, and one case of posttraumatic arthrofibrosis that required surgical release. In 2012, Harrison and associates [29] completed further intermediate follow-up at a minimum of 3 years on 27 of the original 58 patients. The authors identified a significant correlation between fracture complexity and rates of osteonecrosis and posttraumatic osteoarthritis. In two-, three-, and four-part fractures, osteonecrosis rates were 0%, 17%, and 50%, and posttraumatic arthritis rates were 0%, 33%, and 60%, respectively.

Based on the available literature, percutaneous fixation techniques would likely result in satisfactory outcomes for patient KN, with an expected VAS pain score of 1 and a Constant score approximately 82–91% that of the uninjured shoulder. However, CRPP does carry the risk of multiple complications, including superficial pin tract infection, loss of reduction, and pin migration.

External Fixation

Similar to CRPP, external fixation represents a percutaneous method of fixation for proximal humerus fractures. External fixation of proximal humerus fractures involves securing the main fracture fragments with wires or pins that are in turn held together by a rigid assembly external to the skin. Some authors combine this technique with percutaneous fixation of fragment using larger K-wires or Steinmann pins, so the reporting of external fixation in the literature is variable.

In 2010, Brunner and associates [30] reported the outcomes of percutaneous fixation using a proximal humerus-specific external fixator in a prospective case series. Fifty-eight consecutive patients with displaced proximal humerus fractures completed minimum 12-month follow-up. Mean VAS pain score at 1 year was 1.1, and mean Constant score was 88% of that of the uninjured shoulder. Secondary K-wire perforation of the humeral head occurred in 22% of cases. Revision surgery was required in 5 patients (9%).

Gupta and associates [31] published a case series in 2012 analyzing 16 patients treated with Joshi's external stabilizing system (JESS), which includes wires in the humeral head, neck, and shaft connected via an exterior clamp and bar system. There were 11 three-part and 5 two-part fractures. After an average follow-up of 20 months, patients had a mean VAS score of 2.1 and Constant score of 78. Complications included one case of pin tract infection and one case of wire migration, and average time to union was 6.5 weeks.

In 2014, Parlato and associates [32] described their technique of percutaneous reduction with Steinman pins and K-wires followed by application of a Tension Guide Fixator (TGF) in 84 patients (66% two-part and 34% three-part). Healing occurred in all patients by 7 weeks, at which time the fixator and pins were removed in the outpatient setting without anesthesia. No secondary displacement or loss of reduction occurred, and there were no reported infections. At 1-year follow-up, cumulative results (based on Constant, UCLA, Oxford, and Quick-DASH scores) demonstrated good or excellent results in 76/84 patients (90%).

Tension Band Fixation

Fixation using a tension band suture construct has traditionally been used primarily for isolated fractures of the tuberosities. However, in 2003, Park and associates [33] reported the utility of this technique for a variety of displaced two- and three-part fracture patterns. In this series, rotator cuff-incorporating tension band sutures were used to repair 13 greater tuberosity (GT), 9 surgical neck, and 6 GT surgical neck three-part fractures. All fractures achieved radiographic union without AVN. Eighty-nine percent of patients had excellent or satisfactory results at 1-year follow-up, and mean ASES score was 87, with no differences in outcomes between fracture types.

In a 2005 technique paper, Hertel and associates described the use of tension band suture fixation for four-part fractures in osteoporotic bone [34]. Dimakopoulos and colleagues [35] further supported the use of tension band sutures in their 2007 publication, recommending this technique as an inexpensive alternative to plate fixation that still provides sufficient stability to allow early passive range of motion. In a cohort of 165 patients, which included 45 four-part valgus-impacted, 64 three-part, and 56 two-part GT fractures, all patients healed without requiring further surgery with the exception of two isolated greater tuberosity fractures. With a mean follow-up of 5.4 years, malunion occurred in only nine patients (5%). There were 11 cases of AVN (7%), and 4 of these patients had complete subchondral collapse. Mean Constant score for the entire cohort was 91, representing a mean of 94% of the uninjured contralateral shoulder's score.

Bockmann and colleagues [36] conducted a prospective non-randomized trial in 2015 comparing standard stainless steel wire with FiberWire® (Arthrex, Naples, FL, USA) for fixation of the GT as an adjunct to locking plate fixation of displaced three- and four-part proximal humerus fractures. At 6 months the authors found no difference in functional outcomes between the two groups, including VAS pain scores, Constant scores, and patients' abilities to perform ADLs. Both groups had a 20% rate of revision surgery.

Open Reduction Internal Fixation (ORIF)

With the development of improved techniques for internal fixation of fractures during the latter half of the twentieth century, plate fixation of proximal humerus fractures became more widespread. Various methods of conventional plate fixation for displaced proximal humerus fractures have been used successfully, including orthogonally positioned one-third tubular plates [37, 38]. Common problems with these techniques, however, have included loss of fixation and subsequent malunion, owing in part to the poor bone quality in this region, especially among the elderly. Avascular necrosis (AVN) can also occur and may be the result of vascular compromise at the time of the injury, soft tissue stripping during exposure, or a combination of the two. With the advent of fixed-angle plating constructs, specifically anatomically contoured proximal humerus locking plates, these modern implants quickly replaced conventional plating constructs. Locking plates have been shown to be superior to non-locking plates in biomechanical studies, although comparative clinical studies are lacking. Advantages of locked plating constructs (such as decreased rates of screw cutout and hardware failure) [39] made locked plating an attractive option for treatment of proximal humerus fractures, especially in osteoporotic bone. However, complications including loss of reduction, screw cutout, AVN, and infection do still occur following ORIF with locking plates. In fact, Bell and colleagues [40] compared Medicare data from 2004 to 2005 (after the introduction of locking plates) to data from 5 years earlier (before the widespread use of locking proximal humerus plates) and reported a 47% higher rate of early (<12 mo) reoperation in the locking plate cohort compared to patients treated with conventional plates (odds ratio 1.47, $p = 0.043$). (To standardize nomenclature in this chapter, hereafter, ORIF refers to internal fixation with locked plating.)

ORIF: Clinical Outcomes

In an early (published in 2004) retrospective case series of 72 fractures treated with locked plating, Bjorkenheim and colleagues [41] reported an average Constant score of 77 at 1 year with low complication rates. There were two cases of implant failure (2.8%), three cases of AVN (4.2%), and two nonunions. All patients reported a return to their preinjury activity level, and 18 of 23 employed patients (78.2%) returned to their previous occupation.

In 2009, Brunner and coworkers [42] published a larger prospective observational series of 158 fractures and reported much higher complication rates with 25% of patients requiring repeat surgery. Screw perforation occurred in 15%, and AVN occurred in 8%. The fact that each surgeon in the study treated three or fewer patients may account in part for these high complication rates. Despite the high incidence of complications, however, the average Constant score for the entire cohort was 72. In the same year, another multicenter prospective observational study by Sudkamp and coworkers [43] reported a similarly high rate of unplanned reoperation (29/187 or 19%). Sixty-two complications occurred in 52 patients, for an overall complication rate of 28%. Errors in surgical technique accounted for 40% of the complications, with the most common error being intraoperative screw perforation of the humeral head ($n = 21$, 14%).

A 2011 systematic review of locked ORIF by Sproul and coworkers [44] included 514 fractures (34% two-part, 45% three-part, and 21% four-part). The average Constant score was 73.2 at final follow-up for all patients, with more severe fracture types showing lower scores. Neer-type two-, three-, and four-part fracture Constant scores averaged 77.4, 72.4, and 67.7, respectively. There was a high overall complication rate (49%), and 14% of patients required secondary surgery, most commonly due to screw perforation. AVN occurred in 10%, but only 4 of the 51 patients required conversion to hemiarthroplasty (HA). Interestingly, the complication rate decreased from 49% to 33% when fractures fixed with a varus malreduction were excluded.

In 2014, Ockert and coworkers [45] published long-term follow-up data on 43 patients from an original cohort of 121 who underwent proximal humerus ORIF. Average age at time of surgery was 58. At a median follow-up of 10 years, these 43 patients had an average Constant score 84% of that of the contralateral arm. While the average Constant scores improved between 1 and 10 years, scores at both timepoints were highly correlated, suggesting that poor 1-year outcomes may portend poorer long-term function.

ORIF: Fracture Patterns and Technical Considerations

The commonly cited article by Gardner and coworkers [46] in 2007 highlighted the importance of medial calcar status and introduced the concept of medial calcar support. The authors defined medial support as the presence of one or more of the following: anatomic reduction of the medial cortex, lateral impaction of the proximal fragment in the distal shaft fragment, or successful placement of an oblique locking screw into the inferomedial aspect of the humeral head. The authors presented a series of 35 proximal humerus fractures, 18 with medial support and 17 without. Fractures without medial support had less satisfactory reductions, increased rates of screw perforation (29.4% vs. 5.6%), and significantly greater loss of humeral head height (5.8 vs. 1.2 mm) compared to those with medial support. Interestingly, these radiographic differences did not correlate with clinical differences, as there were no differences in rates of union or conversion to arthroplasty. However, the impact of medial support on functional outcomes was demonstrated convincingly by Yang and coworkers [47] in their 2010 publication. In this prospective observational study of 64 consecutive patients, those with medial support had significantly better functional outcomes at 1 year (mean Constant score 81 versus 65, $p = 0.002$). The overall complication rate of 35% included screw cutout in 8% and AVN in 3%. All of the recorded complications occurred in four-part fractures.

In a 2011 RCT, Zhang and associates [48] radiographically assessed the presence or absence of a medial support screw (MSS) in 68 patients with two-, three-, and four-part fractures. At mean follow-up of 30 months, patients who had a MSS were more likely to achieve good-excellent Constant scores than those without a MSS (79% vs. 62%, $p = 0.01$). Screw cutout was significantly more likely to occur in patients without a medial support screw than those with a MSS (23% vs. 3%, $p = 0.036$). The presence of a MSS was particularly useful for preventing varus collapse in three- and four-part fractures. Final neck-shaft angle (NSA) was significantly lower in the –MSS group compared to the +MSS group (123.7 vs. 129.4), indicating a worse average varus deformity. Interestingly, bone mineral density (BMD) did not correlate with loss of fixation in this study.

While valgus-impacted fractures are the most common fracture pattern in the elderly [21], they also tend to have better outcomes than fractures with initial varus deformity. Two publications by Solberg and colleagues in 2009 [49, 50] demonstrated poorer outcomes in fractures with initial varus deformity. Patients with varus/extension deformity had a superior mean Constant score compared to patients with a valgus pattern fracture at an average follow-up 34 months [49]. Additionally, loss of fixation after ORIF only occurred in fractures that demonstrated >20° varus deformity at the time of injury [50]. In a retrospective analysis of 45 fractures in 44 patients published the same year, Lee and associates [51] also showed that a decreased NSA (varus angulation) at the time of injury was predictive of poorer outcomes following ORIF.

In 2010, Olerud and associates [52] evaluated the quality of life and functional outcomes of 50 patients with two-part proximal humerus fractures following treatment with a locked plate. Patients demonstrated progressive improvements in Constant scores at each follow-up visit up to 1 year. However, all HRQoL values ($EQ\text{-}5D_{index}$) were significantly lower than pre-fracture values ($p < 0.001$). This information is important when counseling patients on expectations following treatment of these injuries.

Ockert and associates [53] performed an RCT the same year comparing mono-axial vs. polyaxial locking screws in 66 patients who underwent ORIF. There was no correlation between screw design and secondary varus displacement or screw cutout. Increasing age, fracture parts, and immediate postoperative head-shaft angle (HSA) <130° correlated with further varus displacement and screw cutout. Only 15% of patients with a HSA >130° experienced screw cutout compared to 48% in patients with a HSA <130°. In 2011, Voigt and associates [54] published another RCT investigating the role of mono- vs. poly-axial screws in locking plate fixation of three- and four-part displaced fractures. There were no differences in complications or clinical outcome scores (including Constant, DASH, and simple shoulder test) between the mono- and poly-axial screw groups.

Due to the high prevalence of osteoporosis among patients who sustain proximal humerus fractures, obtaining adequate fixation and screw purchase is often challenging. Multiple techniques exist for augmenting construct strength to minimize postoperative displacement and screw cutout [37, 55]. Fixation can be augmented with placement of synthetic bone substitutes, bone cement, fibular allograft struts [56–58], iliac crest bone graft (ICBG) [59], or endosteal plates [58] into the humeral head or intramedullary canal, providing cortical purchase for locking screws. A 2015 review by Schliemann and associates [55] highlights these techniques and summarizes their impact on radiographic outcomes, namely, improving rates of union and decreasing malunion and screw cutout. However, there remains a lack of high-quality evidence to demonstrate any marked effect of these techniques on functional outcomes.

Current evidence does not demonstrate any significant advantage to early vs. late fixation of proximal humerus fractures. Archer and associates [60] performed a retrospective review in 2016 investigating timing of ORIF in a consecutive series of 22 fractures treated by a single surgeon. There were no differences in rates of AVN between fractures within 72 h of presentation and those fixed after 72 h. Increasing fracture complexity, however, did correlate with a higher AVN rate. In 2015, Siebenbürger and colleagues [61] retrospectively studied a larger cohort of 328 patients. These authors also found no difference in complication rates between patients who underwent ORIF 0–2 days vs. 3–5 days after injury. Delay in surgery past 5 days, however, was associated with increased odds of complications. The median time to fixation for the entire cohort was 3.2 days. Overall, loss of fixation occurred in 13%, screw cut out in 5%, and AVN in 7%.

Deltopectoral Versus Deltoid-Splitting Approaches

There are two main surgical approaches utilized for proximal humerus fracture ORIF: the deltopectoral and the deltoid splitting. Numerous studies describe variations on these techniques and present associated outcomes, but very little high-quality evidence exists. In 2014, Buecking and colleagues [62] published an RCT comparing the 2 standard approaches in 120 patients, 60 in each arm. At 1-year follow-up, there were no differences in Constant scores, VAS scores, or rates of reoperation. The authors also compared the first 30 and second 30 cases in each group to investigate the impact of a learning curve on patient outcomes, but no differences were found.

What's New?

Nonunion rarely occurs in proximal humerus fractures, with one 2015 systematic review of 92 treatment articles citing 0.5% after ORIF [63]. The upper extremity has a favorable blood supply, and the limited weight-bearing requirements of the arm facilitates reliable fracture healing. Nonetheless, nonunion has been reported.

In 2012, Julka and colleagues [64] published a case report documenting a severe adverse inflammatory reaction to BMP-2, which was used as an adjunct to ORIF of a proximal humerus fracture nonunion following unsuccessful nonoperative treatment. The patient developed acute swelling of the chest wall, shoulder, and arm, resulting in near complete occlusion of the axillary vein. Imaging was negative for hematoma, infection, or DVT. The patient responded promptly to high-dose steroids and ultimately went on to heal the fracture, although heterotopic ossification did occur.

You and colleagues [65] recently performed an RCT comparing standard preoperative planning to preoperative planning using a 3D printed model based on injury CT scan in a cohort of 66 three- and four-part fractures. In the 3D CT group, the authors simulated fracture reduction and templated ORIF (including projected screw lengths) on the model. There was no difference in union rates between groups, but 3D CT-based preoperative planning resulted in significantly less estimated blood loss and shorter operative and fluoroscopy times compared to standard preoperative planning. Templated screw lengths were accurate to within 0.1 mm of the actual selected screw lengths. In a 2015 retrospective study, Xia and colleagues [66] reported similar findings with regard to the accuracy of 3D CT-based templates for proximal humerus fracture ORIF.

In summary, ORIF leads to reliable healing, with good to excellent outcomes in the majority of patients. However, complications and reoperation rates remain relatively high despite significant advancements in implants and surgical techniques. If a surgeon plans to perform ORIF of a proximal humerus fracture, advanced imaging with preoperative planning should be considered, and locking plates should be utilized. Proper fracture reduction, including restoration of the neck-shaft angle to >130° and successful achievement of medial support, are essential. Finally, in the setting of severe osteoporosis, impaction, or comminution, augmented fixation may be necessary to minimize the risk of fixation failure and its attendant impact on functional outcomes.

Intramedullary Nail Fixation

Antegrade intramedullary nailing (IMN) of displaced proximal humerus fractures has gained popularity due to its minimally invasive nature and satisfactory outcomes reported in many case series. Early reports in the 2000s showed promising results. Several studies have demonstrated satisfactory to excellent outcomes based on Constant and Neer scores in up to 80% of patients with proximal humerus fractures treated with IMN fixation [67, 68]. However, some surgeons avoid the technique due to the concern for further injury to the rotator cuff during nail insertion and higher reported rates of reoperation.

In 2003, Mittlmeier and coworkers [69] reported on 221 patients who underwent locked IMN. This cohort demonstrated continued functional improvement at 3, 6, and 12 months, with a final Constant score of 86% of the unaffected side in the 50 patients who completed 1-year follow-up. Despite these promising results, which are comparable to other studies, 59 complications occurred in 115 patients at 9 months, for an overall complication rate of 51.3%. The most common complication was screw backout, affecting 23% of patients. AVN developed in nine patients (7.8%), and eight (7.0%) had mild symptoms of pain, and only one required revision to a hemiarthroplasty. Linhart and coworkers [70] reported the outcomes of 51 patients with a minimum of 1-year follow-up after IMN fixation of two-, three-, and four-part fractures. This case series, published in 2007, reported a lower overall complication rate (20% total), with proximal screw loosening again being the most common. Avascular necrosis occurred in four patients (8%), and three (6%) underwent revision surgery for hemiarthroplasty. Patients showed significant improvement in Constant scores at 1 year, achieving an average score of 82% of the uninjured side. Interestingly, there were no differences in functional outcomes between two-, three-, and four-part fractures.

Several other studies in the literature report outcomes and complication rates following IMN fixation of proximal humerus fractures, and significant variability in the data exists. As mentioned above, Linhart [70] found no differences in functional outcomes between fracture types. A similar retrospective study by Kazakos and coworkers [71] in 2007 also reported no difference between patients with two- or three-part fractures. However, in a 2001 retrospective study by Adedapo and coworkers [68], patients with three-part fractures performed better on the Neer shoulder score than those with four-part fractures at 1 year (89 vs. 60). Reported complication rates are as low as 4% and as high as 51.3%, with several studies reporting complication rates of approximately 20% [69, 70]. A 2007 study [72] reported a 45% complication rate, while another in 2011 identified complications in only 4% of patients [73]. All of these studies have limited strength and utility due to the lack of a comparison group.

In 2012, Giannoudis and coworkers [74] published a retrospective trial of 25 patients treated by IMN, with similar complication rates and favorable functional outcomes. The authors did, however, identify an association between age and functional outcomes; patients under 60 years of age achieved significantly better Constant scores than patients 60 and over. In the same year, Thomazeau and coworkers [75] reported on a prospective cohort of 51 patients with 2-year follow-up, including 31 three-part and 20 four-part fractures. The authors demonstrated a 29% rate of malunion and 32% rate of AVN, with no cases of infection, deltoid, or axillary nerve damage. The extent or severity of humeral head AVN correlated with functional outcomes. An average Constant score of 56 was seen with AVN affecting <30% of the head, whereas AVN affecting 30–50% of the head was associated with a mean score of 50, and AVN > 50% resulted in an average score of only 38.

Dall'Oca and coworkers [76] published one of the longest follow-up studies to date for IMN fixation of proximal humerus fractures in 2014. The authors treated 30 patients (average age 75) with two- and three-part fractures. Functional outcomes at 7 years included 73% good to excellent results and a 20% rate of overall complications. These included three cases of screw pullout (10%), two cases of impingement (6.7%), and one case of deep infection (3.3%).

Lopiz and coworkers [77] performed an RCT in 2014 comparing straight vs. curvilinear humeral IMN designs in 54 patients with two- or three-part fractures. There was a trend toward higher Constant scores at 1-year follow-up with straight nails compared to curved (83 vs. 73, $p = 0.25$), and there were significantly fewer rotator cuff symptoms with the straight nail (35% vs. 73%, $p = 0.001$). Final neck-shaft angle was similar, but reoperation rates were significantly higher with the curved nail (42% vs. 12%). These data suggest better functional outcomes and decreased complications with straight nails.

For our patient KN, the particular fracture pattern (with involvement of the greater tuberosity) makes intramedullary nail fixation a less effective treatment option, particularly since additional exposure may be required to ensure secure fixation of the greater tuberosity in order to prevent nonunion. Furthermore, even if a straight IMN design is used, the relatively high incidence of rotator cuff symptoms postoperatively makes IMN fixation less attractive [73, 78].

Arthroplasty

In most proximal humerus fractures, joint-preserving treatment options, whether nonoperative or operative, can be expected to result in satisfactory outcomes. However, in the setting of severe comminution or marked osteoporosis, internal fixation may not be possible or advisable. Furthermore, certain injury patterns, particularly fractures involving the anatomic neck, head-splitting fractures, and some fracture dislocations, have a high risk of AVN, leading to significantly lower functional outcomes [79]. In these circumstances, arthroplasty may be considered. Still, the treating surgeon must exercise caution when deciding to perform a shoulder arthroplasty, as these procedures are not without complication – both intraoperative and postoperative. As the data presented below will demonstrate, the authors feel that arthroplasty should not be considered as a treatment option for KN given her age and fracture pattern – a two-part surgical neck fracture with a minimally displaced greater tuberosity fracture. However, the following treatment options may be appropriate for certain patients, and the full complement of joint-preserving and joint-replacing options must be available to the surgeon treating proximal humerus fractures.

Hemiarthroplasty (HA)

Hemiarthroplasty involves replacement of the humeral head with a metaphyseal or meta-diaphyseal stem, with retention of the native glenoid joint surface and bone. We will review several outcomes and technical considerations reported in the literature pertinent to hemiarthroplasty. Earlier results were encouraging, but more recent reports demonstrate inconsistent outcomes with concern for persistent shoulder dysfunction and pain.

In 1992 Moeckel and coworkers [80] reported on 22 consecutive patients (average age 70) with 5 three-part, 13 four-part, and 4 head-splitting fractures treated with a modular hemiarthroplasty implant. After a mean follow-up of 36 months, based on the HSS scoring system, there were 13 excellent and 7 good outcomes, with only 2 failures. Moderate to severe pain at final follow-up only occurred in those two patients, both of whom were subsequently converted to a total shoulder arthroplasty. Results correlated inversely with age.

Demirhan and coworkers [81] in 2003 retrospectively assessed HA outcomes in 32 patients with mostly four-part fractures and fracture dislocations. After a mean follow-up of 35 months, excellent or good results were obtained in 75% of patients according to Neer's criteria. The mean Constant score was 68, and mean forward elevation was 113°. Only one patient experienced significant residual pain. However, 50% of the patients developed a nonunion or postoperative displacement of the tuberosities, thereby adversely affecting their functional outcomes. The same year, Mighell and coworkers [82] reported similar results in a series of 72 shoulders. At final follow-up, a pain-free shoulder was achieved in 93% of cases, with mean ASES and simple shoulder test scores of 77 and 7.5, respectively. Greater tuberosity malunion and superior migration of the humeral head correlated with worse functional outcomes.

Other studies, however, have failed to demonstrate such a high rate of satisfactory outcomes. In 2002, Boileau and colleagues [83] reported on 66 consecutive patients treated with HA with a wide range of outcomes. Subjectively, 29 patients (44%) were unsatisfied, and average Constant score for the entire cohort was 56. The authors demonstrated that tuberosity malposition or migration, as well as inadequate restoration of the normal relationship between the prosthetic head and the greater tuberosity correlated with unsatisfactory outcomes. Suture fixation near the tendon-bone interface of the rotator cuff should be performed, and the sutures should be tied to the neck of the implant. This way, secure tuberosity fixation can be achieved, and tuberosity healing can occur.

A larger long-term prospective observational cohort study was published by Robinson and colleagues [84] in 2003. The authors followed 138 patients and reported prosthetic survival was 97% at 1 year, 95% at 5 years, and 94% at 10 years. When the Constant score (CS) was separated into subscores, the authors identified that patients often had satisfactory pain relief but poor function, ROM, and strength. Factors that correlated with 1-year CS included patient age, the presence of neurologic injury, smoking, and alcohol use. Anatomic reconstruction and tuberosity healing correlated with higher functional scores as well as improved range of motion.

There are few long-term outcomes of proximal humerus fractures treated with hemiarthroplasty. In general, however, outcomes tend to deteriorate progressively over time. In 2008, Antuna and colleagues [85] reported on 57 patients who completed a minimum follow-up of 5 years (and mean follow-up of 10 years). According to Neer's criteria, results were satisfactory in 27 patients and unsatisfactory in 30. Mean active elevation and external rotation were 100° and 30°, respectively. Revision surgery was required in two cases, and 16% of patients reported moderate to severe pain.

A 2008 systematic review [86] of 810 hemiarthroplasties performed acutely for proximal humerus fractures (ranging from two-part to head-splitting fractures) indicated that most patients report at least minimal pain at final follow-up. Mean Constant score from the included studies at final follow-up was 57 [63]. Infection was not common, with superficial infections reported in 1.6% and deep infection in 0.6% of cases. Complications related to the fixation and healing of the tuberosities occurred in 11% of cases. Heterotopic ossification occurred in 8.8% of cases, but this did not appear to limit function. Despite the minimal pain at final follow-up and the relatively low rate of complications, 42% of patients subjectively rated their results as unsatisfactory. One interesting finding in this study was the low number of cases performed per surgeon per year (average of 3), which may be a contributing factor to the poor patient outcomes.

In one of the few RCTs investigating shoulder hemiarthroplasty patients, Agorastides and colleagues [87] evaluated early (2 weeks) vs. delayed (6 weeks) mobilization after hemiarthroplasty in 49 patients. At 1-year follow-up, there were no differences in Constant or Oxford scores. In the delayed group, one GT migrated, whereas three GTs migrated in the early group. However, this difference was not statistically significant.

Two additional RCTs investigated specific technical considerations in hemiarthroplasty. In 2007, Fialka and colleagues [88] randomized 35 four-part fractures to HA with different GT fixation techniques. Patients treated with HA and rigid wire cabling of the GT to the implant had higher rates of GT healing and significant improvements in ROM in all planes compared to patients who underwent tuberosity fixation with braided suture. In a similarly sized RCT published in 2013 by Soliman and colleagues [89], 37 patients were randomized to HA with or without biceps tenodesis. Performing a biceps tenodesis was associated with improved Constant scores (75 vs. 69, $p = 0.04$) and decreased incidence of pain (33% vs. 16%) at final follow-up. However, there were no differences in shoulder ROM between groups.

In patients treated nonoperatively that develop symptomatic nonunion, delayed HA may serve as a viable option. In 2012, Duquin and colleagues [90] reported on 67 patients, with two-, three-, or four-part proximal humerus fracture nonunions treated with 54 HAs and 13 TSAs. Arthroplasty was associated with improved pain scores (8.3 pre- vs. 4.1 post-procedure), forward elevation (46° pre- vs. 104° post-procedure), and external rotation (26° pre- vs. 50° post-procedure). Anatomic healing of the GT correlated with improved forward elevation. The overall complication rate, however, was relatively high (21%) and included 12 reoperations, 5 of which involved revision arthroplasty. In a 2015 study, LeBlanc and colleagues [91] reported a clear effect on hand dominance and HA outcomes. At mean 4-year follow-up, 25 dominant shoulder HAs demonstrated significantly worse ASES, DASH, and SST scores compared with 36 HA procedures in the non-dominant arm. In addition, subjective outcomes scores correlated more closely with objective scores among patients in whom HA was performed in the dominant arm.

In summary, HA represents an important treatment option in nonreconstructable fractures or when the humeral head is not viable. Several important considerations described above should dictate surgical technique, such as anatomic tuberosity reduction, stable tuberosity fixation, and restoration of appropriate prosthetic height. Based on the evidence, HA is likely to provide pain relief and help patients achieve a reasonable degree of shoulder function. However, subjective satisfaction and restoration of shoulder ROM and strength are less reliable. While studies documenting long-term outcomes are limited, one study reported 10-year prosthetic survival of 94% [84].

Reverse Total Shoulder Arthroplasty (RSA)

Due to the high incidence of tuberosity malreduction and secondary displacement and the correlation of tuberosity complications with poor functional outcomes after hemiarthroplasty, some authors have proposed reverse total shoulder arthroplasty (RSA) as an alternative treatment option for multipart proximal humerus fractures. Due to its unique geometry and medialized center of rotation, RSA does not rely exclusively upon a competent rotator cuff, thereby potentially yielding improved outcomes even in the setting of tuberosity nonunion/malunion or pre-existing rotator cuff dysfunction.

In 2007, Bufquin and colleagues [92] presented their results in a prospective cohort study of 43 consecutive three- or four-part fractures (mean age 78 years). At 22 months, the mean modified CS was 66% that of the contralateral shoulder. Average forward elevation and external rotation were 97° and 30°, respectively. Complications included five cases of neurologic injury (only two of which resulted in persistent parasthesias of the finger tips), three cases of reflex sympathetic dystrophy (RSD), and one dislocation. Radiographs showed a 25% incidence of inferior scapular notching, of unknown significance. Of note, clinical results did not correlate with GT status, and secondary displacement of the GT occurred in 53% of cases. There were no cases of infection or component loosening.

Cazeneuve and colleagues [93] in 2010 reported intermediate term results (mean follow-up 6.6 years) following RSA in 36 patients with a mean age of 75. Although Constant scores decreased slightly from scores at 1 year, they remained satisfactory at 67% of the contralateral shoulder. Complications included four dislocations, two cases of RSD, and one infection. Loosening was seen in two glenoid components and one humeral component. The rate of scapular notching was 53%, but the clinical significance of this finding remains unclear. Performing a biceps tenodesis was associated with improved Constant scores (75 vs. 69, $p = 0.04$) and decreased incidence of pain (33% vs. 16%) at final follow-up. However, there were no differences in shoulder ROM. And although the authors reported radiographic evidence of glenoid loosening in 63% of cases, only one patient went on to develop clinically relevant aseptic loosening at 12 years.

If a patient develops a nonunion after nonoperative treatment or ORIF, RSA for fracture sequelae can significantly improve shoulder function. In 2014, Raiss and colleagues [94] reported the results of 32 patients (average age 68) with three-part fracture nonunions treated with RSA. After a mean follow-up of 4 years, the mean CS improved from 14 to 47. Significant improvements in forward elevation (43–110°) and external rotation (0.5–13°) were also seen. Prosthesis loosening did not occur, despite a 50% incidence of radiographic scapular notching. Overall, there were 13 complications for an overall complication rate of 41%. The most common complication was dislocation, occurring in 34% of cases and requiring revision RSA in 28% of cases. Two years later, the same author published a nearly identical report [95], this time investigating the outcomes of RSA following *four-part* fracture nonunion. Similar improvements in CS and ROM were seen, and subjective satisfaction was good or very good in 89%. Interestingly, the overall complication rate was substantially lower (9.5%).

In 2015, Hussey and associates [96] presented outcomes following RSA for failed ORIF in 19 patients. All measured outcome scores showed statistically significant improvements: ASES scores improved from 28 preoperatively to 50 postoperatively; simple shoulder test scores improved from 0.7 preoperatively to 3.2 postoperatively; and VAS pain scores decreased from 6.8 preoperatively to 4.3 postoperatively. 79% of patients reported good or excellent subjective outcomes, with one patient (5%) reporting a satisfactory outcome and three patients (16%) reporting unsatisfactory outcomes. Similar to the results following RSA for failed nonoperative treatment, complication rates were relatively high (26%) in this cohort. The five complications included one intraoperative fracture, two humeral component loosenings, and two periprosthetic fractures.

Given that the majority of poor outcomes following hemiarthroplasty for complex proximal humerus fractures are related to the rotator cuff/tuberosity dysfunction, RSA, which does not rely upon the integrity or healing of these structures, has obvious advantages. However, as the available literature shows, RSA for primary treatment of proximal humerus fractures is associated with a high complication rate, and long-term outcomes are not yet available. Additionally, numerous studies report a high incidence of scapular notching, particularly with earlier implants and techniques, though the long-term clinical significance of this phenomenon is not yet known. In the presence of an irreparable rotator cuff tear, incompetent rotator cuff, severe osteoporosis, significant fracture and/or tuberosity comminution, delayed presentation, or nonunion, RSA is a reasonable treatment option in an elderly (>70 years of age), low-demand individual. It is important, however, to have an appropriate discussion regarding the relatively high incidence of postoperative complications associated with RSA.

Part 2: Comparison of Treatment Methods

In Part 1, we discussed outcomes and complications associated with the various nonoperative and operative treatment options for proximal humerus fractures. Below, we will review key publications that compare two or more treatment options. Several important randomized controlled trials published recently have equipped the orthopedic provider with better evidence to guide treatment.

Nonoperative Versus Operative Treatment

External Fixation/Tension Band Versus Nonoperative Treatment

In an early RCT from 1988, Kristiansen and associates [97] randomized 31 two-, three-, and four-part fractures to either nonoperative treatment or external fixation. Eleven patients treated nonoperatively completed 1-year follow-up. Nonunion occurred in four patients (two surgical neck and two greater tuberosity), and two patients developed AVN. In the external fixator group, 13 completed 1-year follow-up. There were two nonunions, one case of AVN, and one deep infection. The median Neer score was 60 after nonoperative treatment and 79 after external fixator application. Only 4/11 patients in the nonoperative group achieved satisfactory or excellent results, compared to 8/13 patients in the external fixator group. While these results suggest that external fixator is superior to nonoperative treatment for displaced proximal humerus fractures, the sample size is too small to draw definitive conclusions. In 1997, Zyto and associates [98] randomized 40 patients with displaced fractures (37 three-part, 3 four-part) to either nonoperative treatment or tension band fixation. At 1-year follow-up, the mean Constant score was 60 in the tension band group and 65 in the nonoperative group. No differences were found in pain scores, ROM, strength, or ability to perform ADLs. Complications in the nonoperative group included two cases of posttraumatic arthritis. In the operative group, six patients had seven complications, including infection, AVN, nonunion, posttraumatic arthritis, pulmonary embolus, and K-wire penetration.

ORIF Versus Nonoperative Treatment

In a retrospective matched case-control study comparing 18 fractures treated with ORIF to 18 treated nonoperatively, Sanders and associates [99] demonstrated better ROM (including flexion, abduction, and external rotation) in the nonoperative group. ASES scores were slightly better in the nonoperative group, but the difference did not reach statistical significance. In addition, 10/18 patients (56%) required secondary surgery following ORIF, compared with only 2/18 (11%) in the nonoperative group.

The first prospective RCT specific to displaced three-part fractures comparing ORIF to nonoperative treatment was published by Olerud and associates [100] in 2011 and included 60 patients. While ROM and HRQoL scores were marginally superior in the operative group after 2 years, the differences were not statistically significant. Patients randomized to receive ORIF had a high overall complication rate, with 30% requiring secondary surgery (13% major, 17% minor). Although only 14% of patients in the nonoperative group healed in a relatively anatomic position, functional outcomes following nonoperative treatment were not significantly different than the those following ORIF. This fact illustrates the limitations of using radiographic parameters as a surrogate for functional outcomes.

In 2010, Fjalestad and associates [101] randomized 50 severely displaced three- and four-part fractures to ORIF or nonoperative treatment and evaluated quality-adjusted life years (QALYs) and cost at 1 year. The study demonstrated no differences in either of these primary outcome measurements. However, the authors concurrently published a clinical study using these same patients [102]. At 1 year, there were no significant differences in Constant score or ASES patient self-assessment score, but radiographic outcomes were significantly better in the operative group. In a third publication, Fjalestad and associates [103] demonstrated that there were no significant improvements in functional outcomes between the 1- and 2-year follow-up visits, underscoring the fact that patients make substantial gains in function between 6 and 12 months following injury.

The PROFHER Trial [104]

In an effort to help guide treatment decisions, the UK National Health Services designed and conducted the largest RCT of proximal humerus fractures to date [104]. Thirty-two hospitals recruited patients from 2008 to 2011, including any acute, displaced proximal humerus fracture (within 3 weeks of injury) for which the orthopedic surgeon would consider offering surgical treatment. Since the study was not bound by Neer's criteria for displacement, surgeons could use their own discretion for recommending surgery. Patients were then randomized to either nonoperative treatment in a sling with a standardized PT regimen or surgical treatment. Interestingly, for patients randomized to undergo surgical treatment, determination of the exact procedure to be performed was at the discretion of the surgeon. Patients were followed for 2 years, and patient-reported outcome measures included the Oxford Shoulder Score (OSS) and HRQoL (via the SF-12). 250 patients (77% female) were enrolled, with an average age of 66. Fracture types were evenly distributed between the operative and nonoperative groups. In total, there were 18 one-part, 128 two-part, 93 three-part, and 11 four-part fractures. Surgical treatment consisted primarily of ORIF (83%), but HA (9%), IMN (4%), and other procedures (5%, including suture or screw fixation) were also performed.

The authors found no significant between-group difference in the primary outcomes (OSS or HRQoL) at 2 years or at any other time point. Subgroup analyses by fracture type, age, smoking status, or hospital also failed to identify any significant differences between operative and nonoperative groups. While there was a trend toward a higher overall complication rate in the operative group (24% vs. 18%), this difference did not reach statistical significance. In all, ten medical complications occurred, and all were in the operative group. Surprisingly, secondary surgical treatment occurred at equal rates (9%) in both groups. Mortality rates were slightly higher in the operative group (7.2% vs. 4.0%, $p = 0.27$) but this difference was not significant.

For displaced proximal humerus fractures involving the surgical neck, the authors of the PROFHER trial concluded that operative and nonoperative treatments result in equivalent patient-reported clinical outcomes at 2 years post-injury. In large part, the authors' conclusion is supported by this well-designed, high-quality study. One caveat worth mentioning is the fact that the average age of patients in the study was 66 years. As such, the results of this study are likely more applicable to an older population and may not be generalizable to younger patients with higher-energy proximal humerus fractures.

HA Versus Nonoperative Treatment

Several high-quality studies exist comparing hemiarthroplasty to nonoperative treatment. In 2011, Olerud and associates [105] randomized 55 patients (average age 77) to HA vs. nonoperative treatment. The authors reported a statistically significant difference favoring hemiarthroplasty in the EuroQol (EQ)-5D index (0.81 vs. 0.65, $p = 0.02$), but improvements in Constant and DASH scores at 24 months did not reach statistical significance. The following year, Boons and associates [106] published an RCT comparing hemiarthroplasty to nonoperative treatment for four-part proximal humerus fractures in patients 65 years and older. The authors found no differences in 12-month functional outcomes or pain scores, and patients in the nonoperative group actually had improved abduction strength at 3 and 12 months compared with those who underwent hemiarthroplasty. A third RCT [107] evaluating three-part, four-part, and head-splitting fractures is forthcoming from the Netherlands and Belgium. Radiographic and functional outcomes as well as HRQoL at minimum 2-year follow-up are expected.

IMN Versus Nonoperative Treatment

In 2007, Van den Broek and associates [72] published a retrospective comparative study of displaced three- and four-part fractures treated with either IMN or nonoperative care. Constant scores were actually better among the nonoperatively treated group, and complications occurred more frequently in the IMN group (42% vs. 25%).

Comparison of Surgical Treatment Methods

ORIF Versus IMN

A multicenter prospective study comparing locked intramedullary nailing and locked plating for displaced two-, three-, and four-part proximal humerus fractures was published by Gradl and associates [108] in 2009. While mean Constant scores were not significantly different between groups, there was a trend toward improved functional outcomes in the IMN group. Complication rates were relatively high in both groups, but there were no statistically significant differences. Two years later, an RCT by Zhu and associates [73] comparing these same two methods of fixation found that ORIF was associated with significantly better ASES scores, VAS pain scores, and average supraspinatus strength at 1 year. However, at final follow-up (3 years postoperatively), there were no differences in functional outcomes, pain, or range of motion. ORIF was associated with a significantly higher complication rate (31% vs. 4%), with screw penetration occurring in 5 of 26 cases (19%).

In 2016, an RCT by Gracitelli and associates [109] compared ORIF vs. IMN fixation in 72 patients with two- or three-part fractures. At all time points (3, 6, and 12 months), there were no significant differences in any functional outcomes, including Constant score, VAS, or DASH. Shoulder ROM and postoperative neck-shaft angle were also equivalent between groups. Significantly more complications and reoperations occurred in the IMN group.

ORIF Versus HA

Comparative data on hemiarthroplasty and fracture fixation are very limited. One of the few comparative studies was performed by Bastian and Hertel [110] in 2009, who prospectively compared the outcomes of ORIF ($n = 51$, median age 54, range 21–88) or HA ($n = 49$, median age 66 years, range 38–87) based on an intraoperative assessment of humeral head ischemia. Seventy-six patients completed an average of 5 years of follow-up. The median Constant scores and subjective shoulder values were 77 and 92 after ORIF and 70 and 90 after HA. This study suggests that hemiarthroplasty and ORIF can each be expected to produce satisfactory outcomes. While ORIF may only be utilized in non-ischemic humeral heads, HA may be used even when humeral head vascularity is absent.

In the same year, Solberg and associates [50] designed a retrospective comparative study to investigate outcome following ORIF ($n = 38$) versus HA ($n = 48$) in patients >55 years of age with three- and four-part fractures. Surgeons chose HA when reconstruction was deemed not possible. Mean Constant score was significantly better after ORIF (69) compared to the HA (61). A subgroup analysis within the ORIF group determined that Constant scores were higher in valgus-impacted (75) than in varus (64) fracture patterns and that postoperative fixation loss occurred only if there was initial varus angulation >20°. AVN occurred in six patients (19%) treated with ORIF, all of whom had significantly lower functional scores than patients without AVN. Strength, pain, and ADLs were similar, while ROM was significantly higher after ORIF. Complications were common after ORIF, including screw perforation in six cases, loss of fixation in four cases, and wound infection in three cases. Complications in the HA group included nonunion of the tuberosity in seven patients and wound infection in three patients.

In a 2013 meta-analysis by Gomberawalla and associates [111], the authors analyzed the published literature comparing joint-preserving and joint-replacing procedures (such as HA and RSA) for treatment of proximal humerus fractures, requiring a minimum of 1-year follow-up. The included studies exhibited significant heterogeneity, but still their pooled results are informative. Among the 340 patients who underwent joint-preserving procedures, the average Constant score was 70. However, mean Constant score was only 49 among the 270 patients who underwent shoulder arthroplasty. Independent risk factors for poorer outcomes included increasing age, more complex fracture patterns, and AVN.

Verbeek et al. [112] designed and published the plan for a forthcoming RCT in the Netherlands. The authors plan to randomize acute three- and four-part fractures to either ORIF or HA in patients at least 60 years old. Minimum 2-year follow-up is required, and outcome measures will include DASH scores, pain, subjective satisfaction, ROM, QoL, radiographic alignment and union, and complications.

ORIF Versus RSA

The literature includes limited data comparing these two methods. In 2013, Ocker and associates [113] published data for 24 patients who underwent RSA and compared their outcomes to a matched cohort of 526 patients who underwent ORIF. After controlling for age, gender, and fracture pattern (three- and four-part fractures), the RSA group demonstrated ROM and Constant scores that were not statistically different from the matched ORIF cohort at 1-year follow-up. RSA patients exhibited remarkably good ROM, including an average of 105° of forward flexion, 99° of abduction, 65° of internal rotation, and 22° of external rotation. Surprisingly and in contrast to the literature on the topic, this RSA group experienced zero complications: no dislocations, infections, or reoperations.

In 2014, Fjalestad published a plan [114], known as the Delphi trial, for an RCT comparing ORIF to RSA. The authors will recruit patients with three- and four-part fractures, follow them for 5 years, and measure Constant scores, OSS, QoL, and cost-effectiveness. This study may hopefully provide improved data on the benefits of operative treatment. Ideally. a third arm of nonoperative treatment will be added.

HA Versus RSA

As RSA has gained popularity [115], the quality of the literature investigating this technique has improved as well. In 2009, Gallinet and associates [116] reported a comparative study of 40 patients who underwent hemiarthroplasty or reverse total shoulder arthroplasty. HA patients reported better internal and external rotation, whereas RSA patients demonstrated better shoulder abduction, forward elevation, and Constant scores. No difference was seen between groups with respect to DASH scores. Three HA patients had tuberosity malunions, and 15 RSA patients exhibited scapular notching.

A 2013 prospective comparative study by Cuff and associates [117] followed a group of 47 patients who underwent HA or RSA for treatment of a three-part, four-part, or head-splitting fracture. At 2-year follow-up, RSA patients demonstrated significantly superior outcomes on nearly every scale, including ASES (77 vs. 62, $p = 0.0001$), SST (7.4 vs. 5.8, $p = 0.0062$), tuberosity healing (83% vs. 61%), and forward elevation (139° vs. 100°, $p = 0.0001$). Rates of complications were similar between groups.

In 2014, Sebastia-Forcada published an RCT comparing RSA to HA in 62 patients >70 years of age with three- and four-part proximal humerus fractures. All but one patient completed minimum 2-year follow-up. Compared to those who underwent hemiarthroplasty, patients who underwent RSA were again noted to have significantly superior Constant scores (56 vs. 40), DASH scores (17 vs. 29), forward elevation (120° vs. 80°), and abduction (112° vs. 79°). Tuberosity healing occurred at similar rates in both groups. And while RSA function was not affected by tuberosity nonunion or resorption, patients in the HA group who experienced nonunion or resorption of the tuberosities had significantly worse shoulder function. Six HA patients required revision to RSA for proximal humerus migration and pain. Unfortunately, revision from HA to RSA did not improve function, with a poor average Constant score of 21 among these patients. RSA complications included one dislocation requiring open reduction and one deep infection requiring two-stage exchange and reimplantation. Of the RSA patients completing 40 months of radiographic follow-up, implant survivorship was 96.8%.

In contrast to Cuff and Sebastia-Forcada, a systematic review in 2013 by Namdari and associates [118] reported equivalent outcomes between HA and RSA patients. The authors included Level 1–4 articles reporting on at least ten patients with minimum 6-month follow-up. Outcome scores were pooled from 14 studies, 13 of which evaluated just 1 treatment method. At an average of 30–40 months of follow-up, there were no differences between HA and RSA in average Constant scores, ASES scores, and shoulder ROM. Odds of complications were 4.0 times greater for RSA than for HA.

Summary of Treatment Choice for KN

Historically, conservative management involved extended immobilization, followed by progressive range of motion. Hodgson's RCT [119] determined that early mobilization and PT (compared to waiting 3 weeks) led to less pain with movement, less pain at night, and less frequent sleep disturbances at 2 year follow-up. This study evaluated stable, minimally displaced two-part fractures, similar to that of our patient KN. If KN selects nonoperative treatment, she would likely benefit from early mobilization and supervised PT as opposed to prolonged immobilization. As KN follows-up in clinic, her provider should monitor specific clinical and radiographic parameters, including self-reported function, pain, objective ROM, residual deformity, malunion, tuberosity healing, and AVN. Though the literature shows radiographic outcomes do not consistently correlate with function, tuberosity healing is a notable exception. Healing of the tuberosities is critical to the success of both ORIF and HA, and functional restoration of the rotator cuff is a key component of favorable functional outcomes and ROM. Although the RSA prosthesis seems to obviate the need for tuberosity healing and rotator cuff function, comminuted fractures, especially in the lower demand elderly population, seem to fare similarly whether treated nonoperatively or operatively. Furthermore, risks associated with surgical treatment and its associated complications must be weighed alongside the potential benefits of anatomic reduction with ORIF or improved ROM provided with arthroplasty.

Evidentiary Table and Selection of Treatment Method

The key studies in treating KN are shown in Table 7.1 [6, 8, 12, 48, 53, 62, 73, 77, 98, 100–102, 104–106]. Based on the available literature, the authors feel that the best treatment in this case would be nonoperative treatment, as favorable functional outcomes can be reliably obtained without the risks of complications associated with operative treatment.

Ultimately when cost and postoperative complications are considered, for patients with displaced proximal humerus fractures involving the surgical neck, an initial trial of nonoperative management is reasonable and should be the default recommendation. Patients should be informed that they are likely to have equal outcomes whether they choose surgical or nonsurgical treatment.

Definitive Treatment Plan and Prediction of Outcomes

KN has an isolated two-part proximal humerus fracture with a minimally displaced greater tuberosity that is amenable to nonoperative treatment. Initial immobilization should last no longer than 1 week in order to control symptoms and allow for appropriate pain management. Early rehabilitation should then be started. The available literature is insufficient to allow definitive conclusions as to which treatment offers the best outcome. However, with nonoperative treatment in this patient, it would be reasonable to expect union, a pain-free shoulder and a subjective satisfaction rate in close to 90% of cases.

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Table 7.1 A summary of the most pertinent, high-quality articles for the treatment of proximal humerus fractures

Author (year)	Description	Summary of results	Level of evidence
Lungberg et al. (1979) [6]	Randomized trial	42 patients with nondisplaced fxs treated nonop. with independent exercise vs. conventional PT at 1, 3, 12 months: equivalent functional outcomes	I
Zyto et al. (1997) [98]	Randomized trial	40 patients with 3- or 4-part fxs treated nonop. vs. wire tension band at 1 and 3–5 years: equivalent functional outcomes. More complications with surgery	I
Hodgson et al. (2003) [8]	Randomized trial	86 patients with 2-part fxs treated nonop. and early PT within 1 week vs. after 3 weeks, had less pain, greater function at 16 weeks, similar at 1 year	I
Doetsch et al. (2004) [12]	Randomized trial	30 patients with nondisplaced fxs treated nonop. with 800 IU VitD3 and 1 g Ca vs. placebo at 6 weeks: increased BMD in VitD+Ca	I
Fjalestad et al. (2010) [101]	Randomized trial	50 patients with 3- or 4-part fxs treated nonop. vs. ORIF at 1 year: equivalent QALYs, cost. Similar AVN 13 nonop., 8 ORIF	I
Ockert B et al. (2010) [53]	Randomized trial	36 patients with displaced fxs treated with ORIF monoaxial vs. polyaxial screws at 6 months: no difference in cutout, secondary varus displacement.	I
Olerud et al. (2011) [105]	Randomized trial	55 patients with 4-part fxs treated HA vs. nonop. at 2 years: higher HRQoL (EQ-5D) in HA, similar CS, DASH, and ROM. Additional surgery: 3 HA, 1 nonop	I
Olerud et al. (2011) [100]	Randomized trial	60 patients with 3-part fxs treated ORIF vs. nonop. at 2 years: nonop. better trend (*p* >0.05) in all outcomes (CS, DASH, HRQoL, ROM). ORIF 30% reop	I
Zhu et al. (2011) [73]	Randomized trial	51 patients with 2-part fxs IMN vs. ORIF at 3 years: equivalent CS, ASES, VAS pain, ROM. Complications: ORIF 31%, IMN 4%	I
Fjalestad et al. (2012) [102]	Randomized trial	48 patients with 3- or 4-part fxs nonop. vs. ORIF at 1 year: equivalent CS, ASES, and AVN (8 ORIF, 13 nonop.)	I
Zhang et al. (2011) [48]	Randomized trial	68 patients ORIF w/ vs. w/o medial support screw at 2.5 years: medial screw had higher CS, less failure, maintained better neck-shaft-angle	I
Boons et al. (2012) [106]	Randomized trial	50 patients with 4-part fxs nonop. vs. HA at 3, 12 months: equivalent CS, VAS, SST. One nonop. converted to HA, 1 HA revision	I
Buecking et al. (2013) [62]	Randomized trial	120 patients with displaced fxs ORIF deltoid split vs. deltopec. at 1 year: equivalent revision, CS, VAS. No learning curve effect	I
Lopiz et al. (2014) [77]	Randomized trial	54 patients with 2- or 3-part fxs IMN straight vs. curved at 14 months: straight higher CS, less cuff sx, fewer revisions 12% vs. 42%. Equivalent union	I
Rangan et al. (2015) [104]	Randomized trial	215 patients with displaced fxs nonop. vs. op. (ORIF, HA, RSA) at 2 years: equivalent OSS, SF-12, and complications (PROPHER trial)	I
You et al. (2016) [65]	Randomized trial	66 patients with 3- or 4-part fxs ORIF preop 3D print vs. standard CT: 3D had less OR time, EBL, fluoroscopy	I
Gracitelli et al. (2016) [109]	Randomized trial	72 patients with 2- or 3-part fxs IMN vs. ORIF at 1 year: equivalent CS, DASH, VAS, ROM. IMN higher complication, reop	I

fxs fractures, *nonop* nonoperative, *reop* reoperative, *preop* preoperative, *deltopec* deltopectoral, *sx* surgery

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8 Humeral Shaft Fractures

Basem Attum, Diana G. Douleh, William T. Obremskey, Bill Ristevski, and Jeremy A. Hall

SM: A 34-Year-Old Female with Arm Pain

Case Presentation

SM is a 34-year-old female who presents to the emergency department via EMS complaining of severe arm pain after a high-speed MVA. She denies any loss of consciousness. On primary survey, she demonstrates a GCS of 15 and a patent airway and is hemodynamically stable. On secondary survey, she demonstrates an obviously deformed left arm. Her past medical history is unremarkable. She takes no medications and has no allergies.

On physical examination, she demonstrates a strong radial pulse in the left upper extremity and clear deformity of the left humerus. Her compartments are soft. Neurological examination reveals intact median and ulnar nerve, motor and sensory functions. Examination of the radial nerve reveals decreased sensation over the dorsoradial aspect of the hand, and she is unable to extend her wrist, thumb, or fingers.

Radiographs of the left humerus are demonstrated in Fig. 8.1a, b.

B. Attum · W. T. Obremskey
Department of Orthopedic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA

D. G. Douleh
Department of Orthopedic Surgery, University of Colorado Hospital, University of Colorado, Aurora, CO, USA

B. Ristevski
Division of Orthopedics, Hamilton General Hospital, Department of Surgery, McMaster University, Hamilton, ON, Canada

J. A. Hall (✉)
Division of Orthopedics, St. Michael's Hospital, Department of Surgery, University of Toronto, Toronto, ON, Canada
e-mail: hallj@smh.ca

Interpretation of Clinical Presentation

The patient's findings and symptoms are consistent with an isolated left humeral shaft fracture. However, Adili and associates have demonstrated that a humeral shaft fracture in a patient, which has been sustained in a motor vehicle crash, is an independent predictor for other long bone fractures as well as fractures in the hand. In the multiply injured patient, a humeral shaft fracture is also associated with a greater likelihood of intra-abdominal injury [1]. Therefore, this patient must be carefully evaluated through a focused history and complete physical examination to rule out associated fractures and other injuries, particularly to the head, chest, and abdomen.

The physical examination is consistent with an associated radial nerve palsy. A complete neurological examination is critical to determine the level of injury: a high radial nerve palsy or posterior

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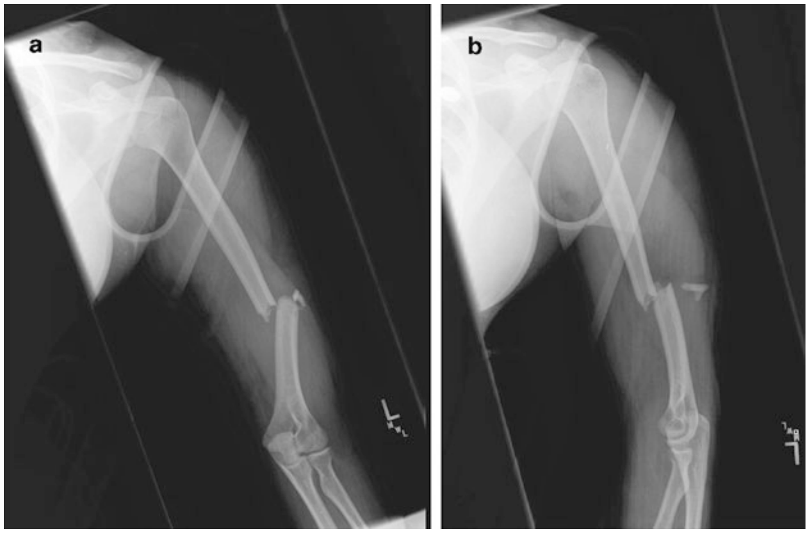

Fig. 8.1 (**a**) AP radiograph of the left humerus. (**b**) Lateral radiograph of the left humerus

interosseous nerve (PIN) palsy. A PIN palsy will exhibit weak wrist extension with radial wrist deviation, as the extensor carpi radialis will typically be spared. A high radial nerve palsy will lack wrist extension altogether. Metacarpophalangeal joint extension should be tested with the wrist in slight extension to inactivate the intrinsic muscles of the hand, which can aid in finger extension when the wrist is in flexion. The vascular examination revealed a "strong radial pulse." Additionally, the ulnar artery pulse should also be palpated. A careful circumferential inspection of the skin is critical to rule out an open fracture.

Radiographs show a transverse mid-shaft humeral shaft fracture, with complete displacement and varus angulation. Initial immobilization via a coaptation splint, sugar-tong splint, or collar and cuff provides some comfort by minimizing fracture motion.

Declaration of Specific Diagnosis

SM is a 34-year-old female who presents with an isolated closed left humeral shaft fracture that is transverse, completely displaced, and in approximately 35° of varus alignment. This fracture also demonstrates a rotational deformity and has slight comminution. She has a high radial nerve palsy with normally functioning ulnar and median nerves and a normal vascular examination.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Reduction and stabilization of the humeral fracture
2. Early mobilization of upper extremity to avoid stiffness/contractures of the ipsilateral wrist, hand, elbow, and shoulder
3. Restoration of radial nerve function
4. Maintenance of muscle strength
5. Return to normal life activities

Treatment options include the following:

Nonoperative treatment

1. Functional bracing
2. Casting

Surgical

1. Plate fixation
2. Antegrade intramedullary nail fixation

3. Retrograde intramedullary nail fixation
4. External fixation

Evaluation of the Literature

Relevant publications related to mid-shaft humerus fractures and associated neurological injuries were located with searches on Medline, PubMed, and the Cochrane Database. Keywords included "fracture," "humerus," "shaft," and "nerve palsy." Subheadings included nonoperative and operative treatment. Searches were limited to humans, the English language, and publication years from 1948 to 2017. Some searches were done with isolated keywords or combined to hone in on relevant articles. Searches were reviewed manually and, if applicable, based on their abstracts. Manuscripts were retrieved and reviewed along with their reference lists.

Detailed Review of Pertinent Articles

The most appropriate treatment for a displaced, angulated, mid-shaft humerus fracture with an associated neurological injury remains controversial. The following discussion evaluates the relevant literature in order to derive the most favorable treatment option for SM.

Nonoperative Treatment

Nonoperative management of humeral shaft fractures is often sufficient for healing and favorable functional outcome. Various casts, splints, and braces have been used in the past for the treatment of humeral shaft fractures. Functional bracing, which allows the shoulder and elbow to remain free from immobilization, avoiding excessive stiffness secondary to treatment, has been the most popular form of nonoperative treatment [2]. The main complications seen with nonoperative treatment are nonunion, malunion, and persistent radial nerve palsy. The largest series of treatment via functional bracing was reported by Sarmiento and associates [3]. They were able to track 620 patients treated for a humeral shaft fracture by functional bracing. The overall nonunion rate in closed and open injuries was less than 2% and 6%, respectively. Malunion was also quantified as 87% and 81% of patients healing with less than 16° of anterior and varus angulation, respectively. Radial nerve palsy was present in 67 patients and recovered in all but one patient. It should be noted that gunshot wounds created by high-velocity weapons and injuries caused by sharp penetration were not included in this study. These results have been replicated by some authors [4–6], while others have not been as successful with nonunion rates in these studies ranging from 10% to 23.2% [7–11]. Some authors have suggested that short oblique fractures particularly in the middle and proximal third of humeral shaft may be at greater risk to develop nonunion [10, 12, 13]. In a recent study by Mani and associates, varus angulation was seen in 99/105 patients with 91% of these in ≤15° and apex anterior angulation seen in 48/105 patients with all angulated ≤10° [14]. Another study by Devers and associates had a malunion rate of 16% with the main reason of dissatisfaction due to residual cosmetic deformity [15]. It has been questioned if and to what degree deformity affects outcome. Shields and colleagues found that residual angular deformity in the sagittal plane up to 18° and up to 27° in the coronal plane had no correlation with patient-reported DASH scores, SST scores, or patient satisfaction [16]. This should help ease the concerns of patients in regard to residual deformity.

Functional bracing has remained the mainstay of treatment for most humeral shaft fractures. SM currently has greater than 20° of malalignment which some authors have reported to be unacceptable [17, 18]. However, a surprising degree of malalignment can be corrected with the use of a functional brace. This correction may take some time to allow gravity to overcome posttraumatic muscle spasm.

It is feasible that all the goals of treatment could be successfully obtained via functional bracing. The literature would support that, in most cases, the radial nerve palsy will recover in this setting [3]. A radial nerve palsy is not an absolute indication for operative treatment. Acceptable alignment, length, and rotation of the humerus could be achieved with functional bracing. A trial of bracing with serial radiographic and clinical examination is a reasonable option. Specific instructions about passive range of motion therapy and an extension splint for SM's fingers and wrist are critical to avoiding stiffness given her neurologic deficit. If an unacceptable reduction persists at 2–3 weeks post-functional bracing, operative management could be considered.

Operative Treatment

Operative indications for humeral shaft fractures include the following [17]:

- Failure to obtain and maintain a closed reduction
  - Shortening >3 cm
  - Angulation >20°
  - Rotation >30°
- Segmental fractures
- Intra-articular extension
- Pathologic fractures
- Ipsilateral fractures (i.e., forearm)
- Bilateral humeral fractures
- Humeral fracture with associated brachial plexus palsy
- Polytrauma
- Open Fracture

External Fixation

External fixation for acute humeral shaft fractures has demonstrated some degree of success, but overall is associated with increased complication rates in terms of malunion, nonunion, iatrogenic nerve injury, infection, and hardware malfunction [19–22]. However, the current literature reflects the fact that most surgeons employ an external fixator for extreme injuries, such as open fractures with massive soft tissue stripping or loss, neurovascularly compromised limbs, and fractures of the humerus caused by high-velocity projectiles. Naturally, patients with a greater zone of injury have poorer outcomes and are susceptible to more frequent and devastating complications compared to patients with less severe injuries.

External fixation has been shown to be useful in dealing with such extreme injuries for multiple reasons: the surgical dissection is minimal; application of an external fixator can decrease operative time, decrease potential blood loss, and can be applied to allow access for vascular and nerve repairs or soft tissue reconstructions. In these situations, external fixation has been used as definitive treatment but also has an established role as temporary fixation before definitive conversion to internal fixation [19, 23–25]. External fixator pin insertion should occur through a mini-open approach, to avoid iatrogenic nerve injury [19, 26].

SM's fracture does not exhibit the characteristics (type II/III open, soft tissue loss, vascular injury, polytrauma) for external fixation. As there is no defined benefit of an external fixator over other surgical techniques in this situation, alternate operative modalities would be more appropriate. In this patient with a closed, nonpenetrating injury, the associated radial nerve palsy is not an indication for external fixation or nerve exploration [27].

Minimally Invasive Plate Osteosynthesis

Minimally invasive plate osteosynthesis (MIPO) is an alternative to conventional methods of operative fixation (ORIF and IMN). This method is technically demanding but in the experienced surgeon's hands has been shown to have equivalent union rates, lower infection rates, and less incidence of iatrogenic radial nerve palsy while providing a better cosmetic appearance [28–31]. Functional outcomes according to UCLA score, Mayo Elbow Performance Index, Constant-Murley score, and HSS elbow scores have been shown to be similar to conventional ORIF [28–32]. The main disadvantages are the complex nature of treatment and risks of malreduction. A prospective cohort study on 53 fractures found that those treated with MIPO had a 40% incidence of postoperative malrotation which can lead to long-term shoulder dysfunction [33].

Plate Osteosynthesis Versus Intramedullary Nailing

Plate osteosynthesis and intramedullary nailing (IMN) remain viable options for humeral shaft fracture fixation. The potential benefits of IMN are the load-sharing properties of the implant, preserved fracture site biology, better cosmetic outcome, decreased intraoperative blood loss, and decreased hospital stay [34]. There have been multiple randomized controlled trials (RCTs) and meta-analyses comparing these treatment techniques [35–42]. The functional outcomes and complication rates vary in the literature. Some studies have shown that there is no difference in union rate and functional outcome [34, 43, 44]. A meta-analysis in 2006 demonstrated that plate fixation was superior to IMN with respect to reoperation rate (relative risk (RR) 0.26 confidence interval (CI) 0.07–0.88, p = 0.03) and significantly lower associated shoulder morbidity (RR 0.10 CI 0.03–0.42, p = 0.002). Bhandari et al. found IMN to be associated with subacromial nail protrusion [36, 45]. Although, complications with each method of treatment have been identified. Technically related complications and shoulder impingement are more common with IMN, while plating has higher rates of infection and postoperative radial nerve palsy (RR = 0.63, 95% CI 0.52–0.76) [46]. Baltov defined technique-related complications seen in IMN as fracture distraction, long proximal interlocking screws, iatrogenic fracture, and countersinking of the nail in the humeral head [47]. Other reports have found less delayed healing, decreased reoperation rates, and shorter union times along with better functional elbow and shoulder outcomes in plating [48–51].

Overall, these RCTs demonstrated that plate osteosynthesis has an advantage over IMN, despite the theoretical advantages of IMN which include smaller incisions, less soft tissue stripping at the fracture site, and better biomechanics compared to plates [11]. However, the nature of the current literature is such that a single study has the power to change outcomes in a meta-analysis, demonstrating the need for a large randomized controlled study with adequate power to address the limitations inherent in the above studies.

There are certain situations where the advantages of a locked IMN outweigh plate osteosynthesis – specifically, multifocal pathological humeral shaft fractures secondary to metastatic disease [52]. In this circumstance IMN can stabilize the bone, allow for early weight-bearing through the extremity, and avoid placing incisions in the area of potential radiotherapy [53]. Other indications for IMN can include segmental fractures with a large intervening segment, morbid obesity, and poor soft tissue coverage. A disadvantage of IMN use has been a higher incidence of shoulder pain and decreased range of motion compared to plate fixation [37, 39, 45].

If nonoperative attempts fail to obtain and maintain an acceptable reduction for SM, either plate osteosynthesis or intramedullary nailing would be reasonable approaches. Two techniques exist for nailing for the humerus: antegrade and retrograde. The major differences include patient positioning as most antegrade nails require entering the shoulder joint versus an approach through the posterior aspect of the elbow joint during retrograde insertion. Operating through the joint, as one could anticipate, can cause complications involving the shoulder and elbow, such as impingement, stiffness, and septic arthritis. Regardless of technique, distal locking screws should be placed with a mini-open technique as percutaneous insertion similar to that used for the lower extremities can lead to iatrogenic nerve injuries [26].

For humeral shaft plate osteosynthesis, when possible, broad 4.5 plates with staggered holes have been favored historically, as experts have suggested that narrow 4.5 plates or smaller 3.5 plates with longitudinally aligned holes could result in longitudinal splits and fracture through the screw holes. No study has ever evaluated this claim. A plate that fits the patient's anatomy and that provides adequate reduction and stability is appropriate. One of the main disadvantages of the conventional open reduction and internal fixation is iatrogenic nerve palsy with the risk varying by surgical approach. The lateral approach has a 20% risk; the posterior approach, an 11% risk; and the anterolateral approach, a 4% risk of iatrogenic radial nerve palsy [54].

Early exploration is suggested in open fractures, irreducible fractures, unacceptable reduction, vascular injury, intractable nerve pain, and nerve palsy after manipulation of distal spiral fractures [55]. In high-energy fractures, where the zone of injury of the nerve is too great to allow useful results from primary repair, exploration allows earlier treatment decisions in terms of subsequent nerve grafting or tendon transfers [27].

A majority of traumatic radial nerve injuries occurs in middle and distal third fractures due to the close proximity of the nerve to the periosteum and piercing of the lateral intermuscular septum [56, 57]. Return of function is largely dependent on the type and mechanism of injury. In closed fractures from low-energy trauma, recovery of the radial nerve is probable as the nerve is usually intact but contused. High-energy trauma and/or open fractures have a higher likelihood of nerve disruption and longer recovery times [27, 58, 59]. A retrospective review looking at open humerus fractures with radial nerve palsy had (9/14) 64% of radial nerves either lacerated or interposed between the fracture fragments. Six regained function after epineural repair, neurolysis, or removal from the fracture fragments without tendon transfer [60].

Evidentiary Table and Selection of Treatment Method

The cornerstone studies related to the treatment of SM are included in Table 8.1 [3, 35–37, 39, 46, 48, 49, 51]. Based on the literature, the authors recommend that SM be treated with a trial of functional bracing. If an acceptable reduction is not obtained or maintained by 2 weeks post-bracing, the authors prefer plate osteosynthesis via an anterolateral approach, which would also allow for a radial nerve exploration if desired to provide prognostic information.

Definitive Treatment Plan

SM's fracture of her humerus on presentation has an unacceptable degree of malalignment. However, proper use of a functional brace has the ability to improve fracture alignment. After a brief (7–10 days) splinting, functional bracing is initiated: it is imperative that the functional brace fits in a snug fashion. As swelling decreases and atrophy occurs, the brace should be adjusted to maintain a tolerably tight fit. The brace will work by compressing the soft tissues around the fracture site and improving the bony alignment via the principle of incompressibility of fluids [61]. Gravity and the alternating forces resulting from active elbow flexion and extension are also helpful reduction aids. However, active shoulder elevation and abduction have been noted to have a displacing effect on humeral fractures [3]. Patients should be instructed not to rest their elbow on the arm of a chair or table, as this can cause further malalignment. In Sarmiento's very large series, 67 patients had an associated radial nerve palsy; of these, 66 patients had recovery of their nerve. Wrist drop splints were not employed, as rapidly regaining elbow extension intrinsically brought the wrist into a neutral position avoiding flexion contractures of the wrist [3]. In SM's case, if a 2–3-week trial of functional bracing results in an unacceptable amount of malalignment, operative fixation is reasonable.

If osteosynthesis is required, our preferred treatment of choice is plate fixation. For plate osteosynthesis, the patient is placed in a semisitting or supine position and appropriately prepared and draped in a sterile fashion. Tourniquet application is not usually possible. Distal fractures of the shaft can be approached posteriorly; however, an anterolateral approach would be appropriate for SM's fracture. The incision centers on the fracture and is approximately 15 cm long. The fascia is incised in line with the skin incision. The biceps is retracted medially, being mindful of the musculocutaneous nerve which lies beneath. Any traumatic injury to the muscle typically can be utilized in the surgical approach. The brachialis is split centrally in a longitudinal fashion. Typically, this muscle has dual innervation by the radial and musculocutaneous nerve and is not rendered functionless by this technique. The radial nerve should be identified in the distal aspect of the wound (as it lies between the brachioradialis and the brachialis muscles), inspected, and protected. It can then be traced back proximally and inspected through the fracture site: this provides prognostic information.

Table 8.1 Evidentiary table: A summary of the quality of evidence for functional bracing and operative fixation via plates or IMN of humeral shaft fractures

Author (year)	Description	Summary of results	Level of evidence
Sarmiento et al. (2000) [3]	Retrospective case series	Followed 620 of 922 patients with a humeral shaft fracture treated by functional bracing. Overall, nonunion rate of 2.6% (<2% for closed and 6% for open fractures). Overwhelming majority of patients obtaining functional range of motion and acceptable alignment	IV
Bhandari et al. (2006) [36]	Meta-analysis	3 RCTs pooling of 155 patients comparing compression plating versus IMN of humeral shaft fractures. RR of reoperation favoring plates of 0.26, 95% CI 0.007–0.9, $p = 0.03$. Also reduced risk of shoulder morbidity favoring plates, RR = 0.10, 95% CI 0.03–0.4, $p = 0.002$	I
Heineman et al. (2010) [35]	Updated meta-analysis (from 2006 above)	4 RCTs pooling 203 patients comparing compression plating versus intramedullary nailing of humeral shaft fractures. No significant differences between implants for total complications, nonunion, infection, nerve palsy, or the need for reoperation	I
Heineman et al. (2010) [39]	(Correspondence) meta-analysis re-updated (from 2010 above)	5 RCTs pooling 237 patients comparing compression plating versus IMN of humeral shaft fractures. Total complication rate significantly lower with plates versus IMN, RR 0.52, CI 0.30–0.91, $p = 0.02$	I
Liu et al. (2013) [48]	Meta-analysis	10 studies pooling 459 cases. No statistically significant difference in nonunion, postoperative infection, and radial nerve palsy ($p > 0.05$). Delayed healing rate of humeral shaft fractures was lower in the plate fixation group compared to IMN (RR = 2.64, 95% CI (1.08, 6.6.49), $p < 0.05$)	I
Ouyang et al. (2013) [49]	Meta-analysis updated	10 studies pooling 439 participants comparing plate vs. nail fixation of humerus shaft fractures. Plating reduced the risk of shoulder impingement, shoulder restriction and had a lower reoperation risk (RR, 1.86 [95% CI, 1.11–3.12]; $p = 0.02$	I
Dai et al. (2014) [46]	Meta-analysis	14 RCTs pooling 727 pts. found that there is significantly higher risk of total method-related complications and shoulder impairment with IMN, while plating was associated with infection and postoperative radial nerve palsy (RR = 0.63, 95% CI 0.52–0.76)	I
Changulani et al. (2007) [37]	Prospective randomized controlled trial	47 (2 lost to follow-up) patients comparing compression plating versus IMN of humeral shaft fractures. No significant differences in function as gauged by ASES score. A shorter time to union was found for IMN group (6.3 weeks vs. 8.9 weeks, $p = 0.001$). Higher infection rate with plating was observed, while patients with IMN have more shortening and loss of shoulder motion	I
Kurup et al. (2011) [51]	Meta-analysis	Dynamic compression plating versus IMN of humeral shaft fractures. IMN associated with shoulder impingement, and decreased shoulder range of motion, and with the need for hardware removal	I

RCT randomized controlled trial, *IMN* intramedullary nailing, *RR* relative risk, *CI* confidence interval, *ASES* American Shoulder and Elbow Surgeons

With a closed injury, it is rare for the nerve to be transected; however, knowledge of the status of the nerve (intact, transected, etc.) will affect future care. Thus, primary repair of a transected radial nerve caused by nonpenetrating trauma has poor results, secondary to the large zone of injury which is fundamentally different compared to an injury that is caused by a sharp instrument [27, 55, 58]. The radial nerve is vulnerable at the fracture site (the probable site of injury in this case) as well as at the distal aspect of the humerus, where the nerve pierces the intermuscular septum and becomes an anterior structure. It is here that the nerve can also be inadvertently damaged by surgical dissection, retraction, or hardware placement.

Once exposure is completed, the fracture ends can be reduced and comminuted pieces large enough to play a role in fracture stability should be reduced and fixed with lag screws. Temporary fixation with Kirschner wires may assist in this process. The authors prefer to use a broad 4.5 low contact dynamic compression plate. Preferably, four screws above and below the fracture for fixation are used, with a minimum of three. Compression mode should be used for the screws if the fracture pattern is stable and amenable. It is imperative to examine the distal edge of the plate to ensure that the radial nerve has not been trapped between the plate and the bone prior to securing the plate.

Fluoroscopy may be used to gauge adequacy of reduction, plate placement, and screw lengths. If there is any question about overall alignment or rotation, flat plate X-rays can be taken intraoperatively, which are superior to the view offered by fluoroscopy. A standard closure is performed.

Postoperatively, patients fixed with plates and screws with good cortical contact are allowed to weight-bear as tolerated through the extremity. Weight-bearing on the upper extremity after humeral plating for patients with concomitant lower extremity injuries has been shown to be safe [34, 62].

Minimally invasive plate osteosynthesis (MIPO) techniques for humeral shaft fractures have been evaluated [28–32, 63–67]. The major perceived danger with this technique is the potential injury to neurological structures, particularly the radial and musculocutaneous nerves and malrotation [33]. Overall, most authors feel that this technique is technically demanding and should be performed by surgeons with experience in the area, and that overall alignment is likely harder to achieve with MIPO techniques.

Predicting Long-Term Outcomes

In the largest series of patients treated with functional bracing after a closed injury, less than 2% of patients had a nonunion [3]. However, some studies have failed to replicate this degree of success [11]. In Sarmiento's series of closed and open fractures, the majority of patients (87% and 81%) had less than 16° of varus and anterior angulation, respectively [3]. In addition, 88.6% and 92.0% had less than 10° of range of motion loss at the shoulder and elbow, respectively [3]. The overwhelming majority of patients returned to activities of daily living. A more recent study found that that 90.9% had residual varus angulation, although only minimal shoulder dysfunction was noted [14]. Although there may be some cosmetic deformity present, it has been shown that residual angulation in the sagittal plane of <18° and 2–27° of angulation in the coronal plane did not have any effect on functional outcome [16].

Plate fixation also affords very good long-term results, with good range of motion of the shoulder and elbow, as typically these joints have not been violated for the fixation of shaft fractures, and early range of motion exercises can be initiated [40]. Conversely, elbow motion can be affected in plating of distal shaft fractures [38]. The overall nonunion rate in a recent review was 5% [68]. A recent meta-analysis found that there is a significantly higher rate of method-related complications and shoulder impairment in IMN compared to plating [46].

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9 Distal Humerus Fractures

Lee M. Reichel, Andrew Jawa, and David Ring

TR: 65-Year-Old Woman with Elbow Pain

Case Presentation

TR, a 65-year-old woman, is brought to the emergency department with arm pain, swelling, and ecchymosis after a fall from a standing height while playing tennis.

On physical examination, she has a strong radial pulse at the wrist and deformity of the right elbow. Radial, median, and ulnar nerve function is normal. The right shoulder and wrist are not tender.

Radiographs demonstrate an intra-articular comminuted distal humerus fracture (Fig. 9.1a, b).

Interpretation of Clinical Presentation

This is a common presentation of an intra-articular fracture of the distal humerus. These fractures are most common in older, osteoporotic individuals.

The medial epicondyle, medial trochlea, and capitellum are all separate fragments, and there is articular fragmentation of the lateral trochlea and extra-articular fragmentation of the lateral column. A CT scan with 3D reconstructions and subtraction of the ulna and radius is useful in understanding the fracture for planning operative treatment. Typically, this is an isolated fracture; however, other injuries in the ipsilateral extremity should be considered. Examination was reassuring that there were no other injuries.

Declaration of Specific Diagnosis

This healthy, active patient has a complex comminuted fracture of the distal humerus creating small articular fragments.

What Are the Treatment Goals and Options?

The goals of treatment are as follows:

1. Stable elbow with limited pain.
2. Return to preinjury activity level.
3. Functional range of motion.
4. Recognize and minimize possible adverse events:
   (a) Heterotopic ossification
   (b) Ulnar neuropathy

L. M. Reichel · D. Ring (✉)
Department of Surgery and Perioperative Care, Dell Medical School at The University of Texas at Austin, Austin, TX, USA
e-mail: David.ring@austin.utexas.edu

A. Jawa
New England Baptist Hospital, Tufts University Medical School, Boston, MA, USA

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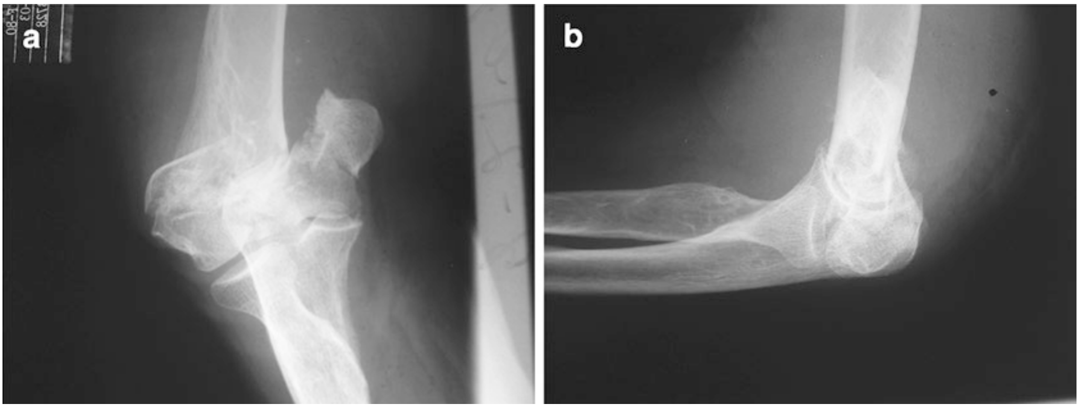

Fig. 9.1 (**a**) AP radiograph elbow. (**b**) Lateral radiograph elbow (Copyright © retained by authors)

   (c) Prominent or irritating implants
   (d) Wound complications:
      (i) Additional surgery may be required to achieve these goals (e.g., removal of symptomatic implants). This may not necessarily represent a problem with the index surgery—it may be an important part of the treatment strategy.

Treatment options include:

1. Nonoperative: casting/immobilization ("bag of bones")
2. Internal fixation (plates and screws; ORIF):
   (a) Orthogonal plating
   (b) Parallel plating
3. Linked total elbow arthroplasty (TEA)

Other important surgical issues:

1. Ulnar nerve:
   (a) In situ release
   (b) Release, mobilization, and:
      (i) Replacement in the cubital tunnel
      (ii) Permanent anterior subcutaneous transposition
2. Exposure:
   (a) Olecranon osteotomy:
      (i) Repair with tension band wiring or plate and screw fixation
   (b) Triceps sparing
3. Heterotopic bone (HO) prophylaxis

Evaluation of the Literature

In order to identify relevant publications on distal humerus fractures, a PubMed search was performed. Keywords included the following: "distal humerus" and "fracture." The search was limited to articles from 1975 to 2011 in English. The search identified 1601 abstracts that were reviewed. From this search, 105 articles were read and selected for the current chapter and reference list. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of the Pertinent Articles

Articles were reviewed for evaluation of surgical approach, treatment options (internal fixation and total elbow arthroplasty), and complications including risk factors.

Nonoperative Treatment

Nonoperative treatment with initial splint or cast immobilization, followed by gentle range of motion, has typically been reserved for the infirm, patients with extensive comorbidities, or those with severe dementia. Although there have not been well-controlled studies looking at operative versus nonoperative treatment in this population, recent studies suggest acceptable outcomes in this patient population.

Desloges and colleagues retrospectively evaluated 32 medically unwell or elderly patients with distal humerus fractures treated with 5 weeks of cast immobilization [1]. Thirteen of 19 patients (68%) had good to excellent results according to patient-reported subjective outcomes (poor/fair/good/excellent). Additionally, Patient-Rated Elbow Evaluation and The Mayo Elbow Performance Index generates scores were 16 (range, 0–83) and 90 (range, 70–100), respectively. Twenty-two of 27 fractures healed (81%). Fracture pattern did not correlate with achieving union. The average flexion arc was 106°.

Aitken and colleagues evaluated 40 patients with distal humerus fractures treated nonoperatively [2]. "Modest" functional results were obtained. At 4-year follow-up, Oxford elbow scores averaged 30 points (range, 7–48), and DASH scores averaged 38 points (range, 0–75). Fracture union rate was 53%. Average elbow flexion-extension arc was within function range. Mortality approximated 40% at 5 years.

Srinivasan and colleagues performed a retrospective cohort evaluation of 29 patients, with an average age of 85 years old, (range, 75–100) with distal humerus fractures who were recommended to have ORIF. Eight underwent nonoperative treatment (medically unfit or declined surgery) allowing the authors to compare the two cohorts. Range of motion (99° vs. 71°) and pain relief (52% vs. 35%) were better in the operative cohort. Complication rates in the operative cohort were similar to cohorts of ORIF in younger patients in other studies. Complications in patients who underwent nonoperative treatment were not specified [3].

Similarly, Robinson and colleagues did not specifically look at the treatment for older patients but evaluated 320 adult patients treated surgically (273 patients) or nonoperatively (47 patients) if the patients were too infirm to tolerate surgery. In patients treated nonoperatively, the union rate was 13% (5/37). Interestingly, four out these five healed following open reduction and bone grafting and one underwent TEA. Again, there are major limitations in applying this information to the population we are evaluating because of inherent bias [4].

Lastly, in 1972, Brown and coworkers described the treatment of 10 patients with intra-articular distal humerus fractures treated with immediate range of motion [5]. Though the age range was from 14 to 80 years old, the four patients older than 65 years old all gained >100° of flexion arc.

Nonoperative treatment is an option, particularly for less active, more infirm individuals. In particular, it is an alternative to total elbow arthroplasty in inactive, infirm patients with poor bone quality or contraindications to anesthetic.

Surgical Approach

There are a number of exposures for treatment of distal humerus fractures including a triceps split (Campbell), a paratricipital exposure (Alonso-Llames), a triceps reflection (Bryan-Morrey), and olecranon osteotomy.

It's preferable to avoid olecranon osteotomy when total elbow arthroplasty (TEA) is a consideration, although it is possible to perform TEA then repair the olecranon osteotomy. TEA is best reserved for infirm, inactive patients with a comminuted intra-articular fracture, although very infirm patients and those dependent on others are best treated nonoperatively. The final decision between open reduction and internal fixation and TEA is sometimes made intraoperatively.

The paratricipital approach allows adequate access for A-type and simple C-type fractures [5, 6].

An olecranon osteotomy provides the best exposure for intra-articular fractures as demonstrated in anatomic studies [7]. However, McKee and coworkers showed in a retrospective cohort study of 25 patients with an open fracture of the distal humerus that the DASH, SF-36 scores, and strength testing were equivalent after ORIF of distal humerus fractures treated with either a triceps splitting approach or an olecranon osteotomy. Patients treated with a triceps-splitting approach had marginally better ROM (10°). Additionally, the osteotomy group had a greater number of secondary procedures, primarily to address prominence of implants used to repair the osteotomy [8].

For the patient under consideration, we would start with a paratricipital approach. If the fracture seemed amenable to fixation, we would convert to an olecranon osteotomy. If not we would proceed with TEA.

Plate Osteosynthesis

Plate fixation is superior to Kirschner wire (K-wire) or screw fixation for C-type distal humerus fractures. Papaioannou and coworkers in a retrospective cohort study of 75 patients compared the outcomes of plate versus K-wire/screw fixation. They found the results to be good or excellent in 88% of patients with stable fixation and early mobilization compared to only 41% with the K-wire/screw fixation and immobilization [9].

Orthogonal Versus Parallel Plating

C-type fractures are often treated with orthogonal plating with a medial and a posterolateral plate. With the advent of stronger, precontoured plates, parallel plating with direct medial and lateral plates is now a well-established option. The strength is roughly comparable, with a slight advantage to parallel plates, probably because the screws are longer (more metal in the distal fragments) [10, 11].

Lee and coworkers prospectively evaluated 67 patients with AO type C fractures in a prospective, randomized, comparative study of parallel versus orthogonal plating [12]. No significant radiological or clinical differences were noted. Implant removal was more frequent in the parallel plating group, and they ascribe that to prominence of the lateral plate.

Shin and coworkers compared perpendicular and parallel plate constructs in a randomized trial of 35 patients (limited power) with C-type fractures [13]. The authors found that range of motion, union times, and Mayo Elbow Performance Scores (MEPS) were similar. All patients received radiation therapy as prophylaxis against heterotopic ossification, but there were only two nonunions: both in the orthogonal plating cohort (not statistically significantly different).

Total Elbow Arthroplasty

Intra-articular distal humerus fractures can be difficult to manage with ORIF, particularly in older patients with poor bone quality. Nonoperative treatment is the best alternative in very infirm patients that are dependent on others. Painful nonunions can be salvaged with linked total elbow arthroplasty.

Linked total arthroplasty is an alternative primary treatment among people who are relatively infirm (about 10–15 years or fewer of life expectancy) and inactive (can accept a 5 pound lifetime lifting limit in the involved hand). Among healthy patients that desire more vigorous use of the arm, ORIF is a better option. Immobilization for a month is reasonable if fixation is tenuous.

McKee and coworkers randomized 42 patients (mean age 78 years) with C-type fractures to either ORIF or TEA [14]. Outcomes were measured by MEPS and disabilities of the arm, shoulder and hand (DASH) scores up to 2 years. Five patients randomized to the ORIF group were converted to TEA at the time of surgery due to extensive comminution. With an intention-to-treat analysis, the two groups were similar. MEPS favored TEA at the 2-year mark; DASH scores were better for the TEA group in the short term, but not at 2 years. The reoperation rate was not statistically different, with 3/25 and 4/15 in the TEA and ORIF groups, respectively. The authors concluded TEA is the preferred treatment in less active, relatively infirm patients when ORIF is not possible due to poor quality and/or comminution.

Two similar level III studies support this conclusion. Frankle and coworkers retrospectively compared 24 women older than 65 years of age who were treated with ORIF or TEA using MEPS [15, 16]. There were 12 patients in each group, and all were followed for at least 2 years. The TEA cohort had 11 excellent and 1 good result without revisions, while the ORIF group had 4 excellent, 4 good, 1 fair, and 3 poor results. All three of the poor results required conversion to TEA.

Jost and coworkers retrospectively reviewed their experience treating distal humerus fractures in patients with rheumatoid arthritis with either ORIF or TEA [16]. They found both groups did well with few complications; however, they favor TEA with more advanced arthritis.

Lastly, Prasad and Dent compared primary with secondary TEA after failed ORIF or conservative treatment. Importantly, both groups included A-, B-, and C-type fractures [17]. Additionally, many of the ORIF groups were treated with K-wire and not plate and screw fixation. The authors found no difference between the two groups in terms of outcome, perhaps because they only looked at short-term outcomes (maximum of 4 years follow-up) and power was inadequate. However, most experts believe that primary TEA has fewer complications and better outcomes than delayed arthroplasty.

Management of the Ulnar Nerve

The ulnar nerve is at risk from both the initial injury and the operative management, and up to 20% of patients may have symptoms after fixation [18]. It seems that the nerve is often dysfunctional after routine intraoperative handling to repair a fracture.

Worden and Ilyas retrospectively reviewed 24 distal humerus fractures. Twelve underwent in situ decompression and 12 underwent transposition [19]. Nine patients had persistent ulnar neuropathy (four following in situ decompression and five following transposition). No significant difference was notable between the two groups.

Ruan and coworkers randomized 29 of 117 consecutive patients (level II evidence) with preoperative symptoms of ulnar neuropathy to either in situ release or anterior subfascial transposition [20]. This trial is very unusual given how rarely anyone else diagnoses preoperative ulnar neuropathy. Preoperative ulnar neuropathy seems uncommon and also difficult to assess. The trial should be interpreted with this caveat in mind. None of the 88 patients without preoperative symptoms had documented postoperative neuropathy. That's a surprising result given that ulnar nerve dysfunction is so common after fixation for a distal humerus fracture. Thirteen of 15 patients in the transposition group compared to 8 of 14 in the in situ release group had improvement in symptoms. The authors recommended anterior transposition in patients with preoperative symptoms.

Chen and associates in a retrospective cohort study compared 89 patients who had not received a transposition to 48 who did [21]. The incidence of ulnar neuritis was higher in the transposition group (33%) compared to the in situ release cohort (9%). Ulnar nerve transposition had nearly four times greater incidence of ulnar neuritis.

In a similar level III study, Vazquez and associates found in 69 patients that transposition did not affect the rate of postoperative ulnar neuropathy [18]. Fourteen of 69 patients (20%) had documented postoperative ulnar nerve dysfunction.

Heterotopic Ossification

The use of routine heterotopic ossification with nonsteroidal anti-inflammatories (NSAIDS) or *limited* field radiation is neither currently supported nor refuted by the current literature with mainly level 4 case series. However, the use of radiation therapy is currently not recommended.

Wiggers and associates retrospectively evaluated 284 elbow fractures to identify patient-related demographic factors, injury-related factors, and treatment-related factors associated with the development of motion restricting heterotopic ossification [22]. Ulnohumeral dislocation, delay in time to surgery, and multiple surgeries within 4 weeks of injury were risk factors identified with development of motion restricting heterotopic ossification. Notably, these factors account for only 20% of the portion of the variation among patients with elbow fracture who develop heterotopic ossification. A large proportion remains unexplained.

Abrams and associates retrospectively evaluated 159 patients with an intra-articular distal humerus fracture [23]. They found that the presence of an AO C3 fracture significantly correlated with the formation of heterotopic ossification and return to the operating room for resection. Additionally, in 86% of cases, the heterotopic bone was noted on 2-week postoperative radiographs.

Hamid and associates conducted a randomized trial at three medical centers comparing single-fraction radiation therapy to no prophylaxis in acute elbow trauma [24]. The study was stopped early because there were 8/21 nonunions in the radiation group, compared to 1/24 in the control group. In a clinical situation, in which union may be tenuous, his negative effect on bone healing is an important consideration regarding the routine use of this modality to prevent HO formation.

Other Adverse Events

Obert and associates evaluated 497 distal humerus fractures in patients aged 65 and older retrospectively and 87 prospectively [25]. In the retrospective group, 34 received nonoperative treatment, 289 internal fixation, and 87 TEA. In the prospective group, 22 received nonoperative management, 53 internal fixation, and 12 TEA. Complications included neuropathy, mechanical failure, infection, and wound problems. The complication rates were 30% and 29% in the retrospective and prospective groups, respectively. The nonoperatively treated fractures healed, usually with malalignment. In the internal fixation group, the complication rate was 44% and in the TEA group, complication rate was 23%. The authors noted that although complications with TEA were less frequent, they were often more severe and more difficult to treat. Although the authors did not elaborate, we agree that complications related to TEA such as infection which may require prosthesis removal and resulting flail elbow can be difficult to manage. In fact, we feel that either antibiotic suppression or allowing a persistent draining sinus is useful as an alternative to explanting an infected TEA. Periprosthetic fracture and aseptic loosening are also difficult problems in TEA to manage.

Lawrence and associates evaluated 89 operatively treated distal humerus fractures in patients average aged 58 [26]. Fourteen patients (16%) developed major wound complications treated with soft tissue coverage procedures. Grade 3 open fractures and the use of a plate to stabilize an olecranon osteotomy were independently associated with wound complications. Fortunately, healing rates and range of motion appear to be unaffected by major wound complications.

Werner and associates reviewed 6928 patients with distal humerus fractures treated with ORIF or TEA [27]. Complications were divided into local (postoperative stiffness and infection) and systemic (PE, DVT, acute myocardial infarction, respiratory failure, acute postoperative CVA, UTI, pneumonia, acute renal failure, and cholecystitis). Obese patients undergoing ORIF (4215) had a 2.5 times greater risk of local complications and a 5.6 times greater risk of systemic complications. Among patients undergoing TEA (2713), obesity was associated with a 2.6 times greater risk of local complications and a 4.4 times greater risk of systemic complications.

Literature Inconsistencies

Although a few randomized trials can guide our management of the patient in this case, these studies are underpowered and need validation with additional trials. Most of the questions, however, in our management of this patient have inconclusive answers or are based on lower quality evidence.

Evidentiary Table and Selection of Treatment Method

The ideal treatment for this patient would be an attempt at initial ORIF, with mobilization of the ulnar nerve to protect it with or without permanent transposition. Fractures that heal after ORIF are allowed full weight bearing. TEA is for infirm, less active people, but the most infirm and dependent people should be treated nonoperatively. Key studies supporting the management of TR are noted in the evidentiary table (Table 9.1) [14, 15, 21, 24, 26].

Definitive Treatment Plan

Stable fixation helps allow immediate functional use of the arm and range of motion exercises. Two to 4 weeks of immobilization are advised if fixation is tenuous. The patient is placed in a lateral position. If a large image intensifier is used, the patient can be placed on a radiolucent table with the contralateral arm placed on an arm board away from the imaging field. One of us always uses the small image intensifier, and no special table is needed.

Table 9.1 Evidentiary table: A summary of the quality of evidence for treatment of C-type distal humerus fractures in patients older than 65 years of age

Author (year)	Description	Summary of results	Level of evidence
McKee et al. (2009) [14]	Randomized trial	42 patients >65 years old with C-type fractures treated with ORIF or TEA. MEPS favored TEA cohort at 2 years	II
Frankle et al. (2003) [15]	Retrospective cohort	24 women >65 years old with C-type fractures treated with TEA had fewer complications and better MEPS than ORIF cohort	III
Chen et al. (2010) [21]	Retrospective cohort	137 patients with and without ulnar nerve transposition with distal humerus fracture showed an increase incidence of neuritis with transposition	III
Hamid et al. (2010) [24]	Randomized trial	Postoperative radiation therapy acutely in elbow trauma increased nonunion rates in 45 patients. The trial was ended early because of the results	II
Lawrence et al. (2014) [26]	Case series	89 operatively treated distal humerus fractures. 16% developed major wound complications treated with soft tissue coverage procedures. Grade 3 open fractures and the use of a plate to stabilize an olecranon osteotomy were independently associated with wound complications. Healing rates and range of motion appear to be unaffected by major wound complications	IV

A posterior skin incision with full thickness fasciocutaneous flaps is utilized identifying the ulnar nerve and unroofed. If the nerve is moved to protect it and to get better fixation on the medial side, then it can either be replaced at the end of the surgery or left transposed anterior to the medial epicondyle. On the one hand, if future surgery is needed for implant removal or to ameliorate stiffness, non-transposed nerves may be easier to locate secondary to native positioning. On the other hand, a nerve replaced in the groove might be at greater risk of irritation from implants.

The triceps is mobilized using a paratricipital approach initially in order to determine if the fracture is amenable to ORIF. If further exposure is necessary, the olecranon can be cut and mobilized. Fixation is performed with either orthogonal or parallel plate configuration with our preference being parallel plating, especially for more distal fractures. The osteotomy is fixed with either a tension band or plate.

Removal of the distal fragments and cemented TEA is performed from the medial side if fixation is not possible. Postoperatively, the patient starts early range of motion with gravity-assisted extension immediately with NSAID, HO prophylaxis considered based on comorbidities.

Long-Term Outcomes

Both McKee and associates and Frankle and colleagues show that the functional scores of TEA are better than ORIF at 2 years [14, 15]. However, the major complications (infection, triceps detachment, and early loosening) are worse for TEA and more difficult to salvage. The long-term outcomes of TEA are unknown. Additionally, patients should be aware of weight-bearing guidelines with TEA as part of shared decision-making. Arthroplasty is best limited to patients with about 10–15 more years or fewer of life expectancy who have limited functional demands [27]. Doornberg and colleagues have shown excellent long-term (12–30 years) results of ORIF in younger patients [28]. There are no long-term results of ORIF for patients >65 years of age.

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Elbow Fracture Dislocation

10

Chad M. Corrigan, Clay A. Spitler, and Basem Attum

SL: A 44-Year-Old Male with Arm Pain

Case Presentation

A 44-year-old male presents to the emergency department via EMS after a falloff of the back of a flatbed truck approximately 8 feet and landing on his right upper extremity. His only complaint is right arm pain and deformity. He denies loss of consciousness or pain in any other extremities. On primary survey his GCS is 15, his airway is patent, and he is hemodynamically stable. Secondary survey demonstrates a deformity of the right upper extremity at the elbow and a 2 cm laceration over the dorsal proximal forearm with egress of fracture hematoma. There is no gross contamination at the level of the open wound. He has a palpable, symmetric radial pulse. He has no motor or sensory deficit. The dorsal and volar forearm compartments are soft and compressible.

Injury radiographs are demonstrated in Fig. 10.1a, b; radiographs after closed reduction are demonstrated in Fig. 10.2a, b.

C. M. Corrigan (✉)
Wesley Medical Center, University of Kansas – Wichita School of Medicine, Wichita, KS, USA

C. A. Spitler
Department of Orthopedic Surgery, University of Mississippi Medical Center, Jackson, MS, USA

B. Attum
Department of Orthopedic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA

Interpretation of Clinical Presentation

The patient's clinical presentation, physical exam, and radiographs are consistent with an isolated elbow fracture dislocation. A thorough history should include details of how the incident occurred along with a complete physical exam to identify any other injuries. Neurologic and vascular status along with the condition of the skin should be evaluated. Although this patient has an isolated injury, associated injuries can occur up to 20% of the time. Associated injuries usually involve the ipsilateral extremity but can involve other body areas, particularly in high-energy injuries. Wolfgang and colleagues reported common concomitant injuries, including longbone fractures, head injuries, thoracic and abdominal solid organ injury, and neurovascular injuries [1].

Standard radiographs for this type of injury are AP and lateral views of the elbow. Other radiographs that should be obtained are AP and lateral views of the shoulder, forearm, and wrist to identify any other injuries.

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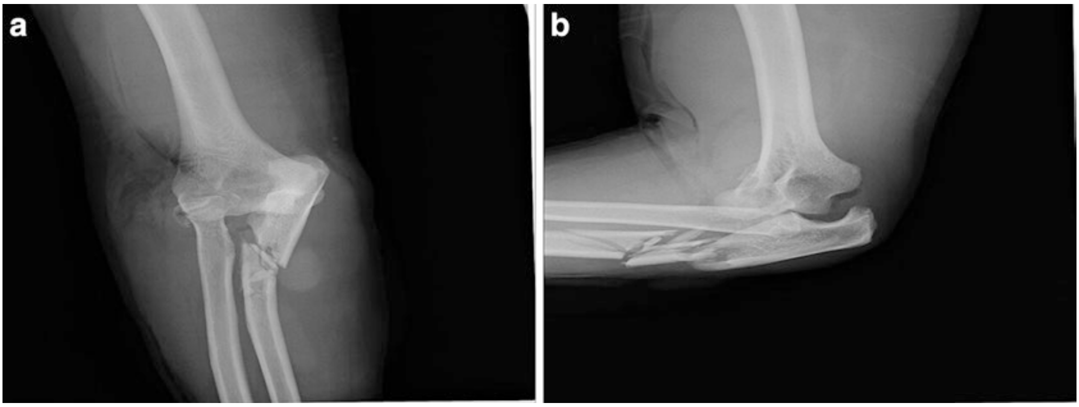

Fig. 10.1 (**a**) Preoperative AP radiograph of the right elbow. (**b**) Preoperative lateral radiograph of the right elbow

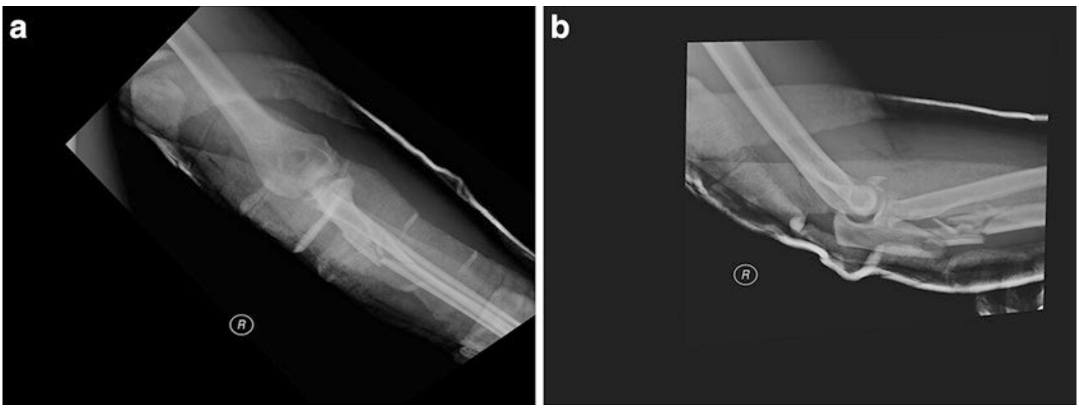

Fig. 10.2 (**a**) Postreduction AP radiograph of the right elbow. (**b**) Postreduction lateral radiograph of the right elbow

Declaration of Specific Diagnosis

S.L. is a 31-year-old male that presents with an elbow fracture dislocation.

Brainstorming: What Are Treatment Goals and Options?

Treatment goals consist of the following:

1. Anatomic restoration of articular surfaces of both ulnohumeral and radiohumeral joint
2. Restoration of both bony and ligamentous elbow stability in flexion and extension
3. Minimizing further soft tissue injury
4. Allowing for early functional rehab and range of motion to prevent stiffness

Treatment options include the following:
Conservative/nonoperative treatments:

1. Casting/splinting until bony and/or soft tissue consolidation allows for ROM

Surgical:

1. Immediate open reduction and internal fixation (ORIF)
   (a) With or without prosthetic radial head replacement
2. Staged ORIF

3. External fixation (hinged or static)
4. Ligamentous repair (acute) or reconstruction (delayed)

Evaluation of the Literature

In order to identify pertinent articles on elbow fracture dislocation, a PubMed search was performed. Keywords used in the search included "elbow fracture dislocation," "operative treatment of elbow fracture dislocations," "open reduction and internal fixation," "conservative management," and "nonoperative management." The search was limited to clinical trials, meta-analysis, randomized controlled trials, review articles, and journal articles in the English language and those that only involved human subjects. Three hundred twenty abstracts were identified. Eighty-five articles were then read and reviewed. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

There are several treatment options for this patient with an elbow fracture dislocation. The following discussion signifies the current literature which identifies optimal treatment.

Nonsurgical Treatment

Fracture dislocations of the elbow with involvement of the radial head, proximal ulna, and the associated ligamentous complex are often referred to as "terrible triad" as they can often lead to a poor prognosis without proper management. With higher-energy injuries, there can be proximal ulna and/or olecranon involvement as well. Most of these fractures are highly unstable and thus often require surgical stabilization of one or more of the injured components. A small subset of patients with this injury can be treated nonoperatively and still expect a good functional outcome. While optimal surgical management of elbow fracture dislocations has not been clearly established in the literature, there are some specific clinical criteria that must be met to proceed with nonoperative treatment [2]. Criteria for nonoperative management include (1) the ulnohumeral and radiocapitellar joints must be reduced without subtle subluxation on all views and with ulnohumeral distance <4 mm on the lateral view and (2) the elbow must remain concentrically reduced in an arc of motion from full flexion to ~30° short of full extension within 10 days of injury [3]. Radial head or neck fractures must not cause a mechanical block to pronation or supination [4]. The coronoid fracture must be small (Regan-Morrey type 1 or 2).

Chan and colleagues performed a retrospective cohort study on 11 patients age 26–76 with terrible triad injuries treated nonoperatively who met these criteria. At the last follow-up, elbow ROM was 134 +/− 5° flexion, 6 +/− 8° extension, 87 +/− 4° pronation, and 82 +/− 10° supination. Four patients developed arthritis not requiring treatment. Strength assessments compared to the contralateral elbow were 100% flexion, 89% extension, 79% pronation, and 89% supination. Mean +/− SD disability of the arm, shoulder, and hand (DASH) score was 8.0 +/− 11.0, and mean Mayo Elbow Performance Instability (MEPI) score was 94 +/− 9. One of the 11 patients underwent surgical stabilization for early recurrent instability, and another patient had arthroscopic debridement of heterotopic bone [3].

There have not been any well-controlled studies looking at operative versus nonoperative treatment of complex elbow fracture dislocations. In a very select patient population, conservative treatment can be successful. CT scan is recommended to verify articular congruity and joint reduction if there is any question on standard radiographs. Stable arc of motion may have to be proven intraoperatively with fluoroscopy under sedation if too painful for the patient in the emergency room. While there is no evidence-based literature to suggest a ROM arc acceptable for closed treatment, it is recommended that the elbow is stable and concentrically reduced up to 30° short of terminal extension. If all nonoperative criteria are met, we recommend a posterior resting splint with medial and lateral side bars at 90° of flexion for 7–10 days. It is imperative to limit time spent in the splint to prevent elbow stiffness. This also allows for soft tissue swelling resolution, pain control, and early healing of soft tissue/ligamentous structures. We then progress to early physical therapy with active range of motion (AROM) and passive range of motion (PROM) within a stable arc and progress weekly until maximum mobility is restored. If at any time during nonoperative treatment these criteria fail to be met, serious consideration must be made for surgical reduction and stabilization.

Surgical Management

Most complex elbow fracture dislocations must be treated surgically to obtain and maintain elbow stability allowing for early functional range of motion. Complex elbow fracture dislocations should be treated surgically when nonoperative criteria are not met, with open soft tissue injuries, and when neurological or vascular injury is present [2]. The surgical stabilization of complex elbow fracture dislocations is often broken into three specific but separate components: radial head/neck fracture fixation or prosthetic replacement, proximal ulna (both olecranon and coronoid) stabilization, and ligamentous repair or reconstruction. While each component is treated individually, they must all be addressed as a functional unit. We will thus discuss a fragment-specific approach to the complex elbow fracture dislocation as part of a systemic approach.

Radial Head

Surgical options for treatment of isolated radial head fractures are excision, ORIF, and prosthetic replacement. However in the setting of complex elbow fracture dislocations, the radial head must not be excised without replacement [4]. The radial head provides key and critical roles in the stability of the elbow. With a medial collateral ligament (MCL) injury, the radial head provides support to valgus instability. Further, if the lateral collateral ligament (LCL) is repaired or reconstructed, it provides a tension force on the ligament to prevent varus and posterolateral instability. With a coronoid fracture, the radial head provides buttress support to posterior subluxation of the ulnohumeral joint. Therefore, in the setting of the complex elbow fracture dislocation with concomitant injuries to the radial head, coronoid, and ligamentous complex, isolated radial head excision is not recommended. It should be noted, however, that in the setting of a terrible triad or fracture dislocation injury, the best treatment of radial head injuries remains unanswered [2]. Ring and associates studied 56 patients with *isolated* intra-articular radial head fragment after ORIF. Thirty patients had a Mason type 2 (partial articular fracture), and 26 patients had a Mason type 3 (complete articular) injury. Four of 15 comminuted Mason 2 fractures had poor results with <100° of forearm rotation, and all 4 were associated with fracture dislocations. All 15 of noncomminuted Mason 2 fractures had good outcomes. Fourteen of the Mason type 3 injuries had more than 3 articular fragments, and 13 of these patients had unsatisfactory results (defined as failure of fixation or nonunion requiring secondary surgery for radial head excision). Twelve of the Mason type 3 injuries had two or three large fragments. Of the 12, none had failure, one had nonunion, and all had >100° of forearm rotation. Their data suggest that ORIF should be reserved for minimally comminuted radial head fractures with three or fewer articular fragments [5]. Further, Bain and coworkers recommend radial head replacement in the context of complex elbow instability when there is a radial head "rim fracture" that consists of 30% or more of the articular surface that cannot be adequately reconstructed [6].

Leigh and coworkers performed a retrospective case-control study on 23 patients with a terrible triad injury. Thirteen patients had ORIF of the radial head, while 11 had radial head replacement. The coronoid and the lateral ligament complex were also repaired in all cases. Mean flexion was 135° (110–145), and mean extension was 8° (0–40). No patients had long-term instability. No significant differences were found between variables of age, range of motion, American Shoulder and Elbow Surgeon score, satisfaction score, arc of motion, or length of follow-up. The only significant difference was the radial head replacement group scoring higher on the DASH. When stability of the elbow is obtained by fixation of coronoid and ligament complex(es), either replacement or ORIF of the radial head can achieve good range of motion [7].

Olecranon/Proximal Ulna/Coronoid

Complex elbow fracture dislocations can have many variations of proximal ulna fracture patterns, and these fracture patterns often indicate the pattern of instability which can be helpful in surgical planning. Mellema and coworkers reviewed CT scans from 110 patients with coronoid fracture components of their complex elbow instability pattern. They performed 3D mapping of the coronoid fracture lines and found significant associations between specific coronoid fracture type and elbow fracture dislocation pattern. Significant associations were found between O'Driscoll type 1 fractures, terrible triad fracture dislocations, and posterior Monteggia fractures with elbow dislocation. Type 2 fractures were associated with varus posteromedial rotational instability injuries, and type 3 fractures were associated with olecranon fracture dislocations [8]. Monteggia fracture dislocations often involve only the proximal diaphysis or metaphysis of the ulna while sparing the greater sigmoid notch. Conversely, transolecranon fracture dislocations often disrupt the greater sigmoid notch, but the ulnar metadiaphysis remains intact. Furthermore, in Monteggia fracture dislocations, the proximal radioulnar joint is disrupted, and the ulnohumeral joint often remains reduced. In the transolecranon fracture dislocation, the ulnohumeral joint is disrupted, but the proximal radioulnar joint and associated ligamentous restraints of the elbow often remain intact. This distinction is necessary because of its treatment implications. While there is a relative paucity in the published literature regarding the optimal treatments of the proximal ulnar fracture, there are a few important publications that can guide us.

Doornberg and coworkers performed a retrospective review of 26 fracture dislocations of the elbow all with olecranon involvement, 10 had anterior radial head dislocations and 16 were posterior. All patients with posterior radial head dislocation had coronoid involvement, but only five of the ten anterior dislocations had coronoid involvement. One of 10 patients with anterior and 13 of 16 patients with posterior injuries had fractures of the radial head. All patients underwent surgical reconstruction through a dorsal approach. Combinations of 3.5 LCDCP and 1/3 tubular plates were used, as well as tension band wires. No ligamentous reconstructions were required. Five unsatisfactory results occurred in patients with inadequate coronoid fixation (3/5) and/or proximal synostosis (3/5). In transolecranon fracture dislocations, the anatomic reduction and stabilization of the greater sigmoid notch and the bony coronoid fracture are the focus. Of particular note is the much higher incidence of both radial head and coronoid injuries with posterior fracture dislocations [9]. Subsequent critical commentary to this study noted that the 13 patients with posterior dislocations and radial head fractures had worse clinical outcomes based upon American Shoulder and Elbow Surgeon score, more limited ROM (than the patients with anterior dislocations), and more degenerative arthrosis. Of note, five patients with posterior dislocations had radial head excision without replacement, and four had nonanatomical reduction of the radial head. In the setting of complex elbow instability, this commentary again highlights the importance of not only proximal ulnar reconstruction but also lateral column stabilization and avoidance of radial head excision [9].

Ring and coworkers performed a retrospective case series on 17 patients with anterior transolecranon fracture dislocations, 14 of which had complex comminuted fractures of the proximal ulna. Sixteen of the 17 injuries were from high-energy trauma. Similar to Doornberg's study, only two had radial head fractures, but eight had a large coronoid fragment that required separate fixation. All ulna fractures were treated surgically; 15 of the 17 were treated with plates (3 with 1/3 tubular or semitubular plates, others with 3.5 mm plates), and 2 were treated with tension band wires. Radial head fractures were treated with partial or complete excision. Two patients required early revision, both treated with 1/3 tubular plates that had to be revised to 3.5 mm plates. Average elbow flexion was 127° (range 100–140), and average flexion contracture was 14° (range 0–40). Only three patients lacked more than 20° of pronation or supination. There was no instability. This study shows the importance of concomitant coronoid and olecranon fixation and stabilization with at least a 3.5 mm plate (not 1/3 tubular plate or tension band fixation) [10].

Of particular importance when treating complex proximal ulnar fractures is the anatomical variance of the proximal ulna. The proximal ulna is most often *not* straight, and this must be understood [11, 12]. Grechenig and Sandman have performed cadaveric studies to analyze the importance of recreating this anatomical variation to prevent iatrogenic instability of the radiocapitellar joint. Grechenig and colleagues found a mean varus angulation of the proximal ulna of 17.5° (11–23°) as well as an apex dorsal angulation of 4.5° (1–14°). Similarly, Sandman and colleagues found the average varus angulation of 15° and an apex dorsal angulation of 6° that they termed the proximal ulna dorsal angulation or PUDA. This variation is extremely important when reconstructing a comminuted metadiaphyseal proximal ulna segment. If a straight non-contoured plate is used, it will often cause subluxation/dislocation of the radial head. Thankfully, most modern implants account for this curvature. When reduction or anatomical variation is in question, we recommend contralateral preoperative elbow films of the uninjured extremity to use as a template for accurate reconstruction.

Fracture morphology of the coronoid process fracture can also guide the surgeon in distinguishing between an anteromedial facet fracture associated with varus posteromedial instability and the relatively small and transverse coronoid tip fracture seen in the so-called "terrible triad" injury. This distinction helps the surgeon to understand the fracture instability pattern and develop an appropriate surgical plan to address each of the components.

The varus posteromedial rotatory instability pattern is characterized by an anteromedial facet fracture of varying size with an associated LCL injury. The injury occurs when a varus load is applied to the elbow and begins with an avulsion of the LCL and progresses as the trochlea causes a fracture of the anteromedial coronoid. This results in ulnohumeral subluxation, and if the forearm further pronates, the coronoid will dislocate posterior to the trochlea [13]. Doornberg and Ring reviewed 18 anteromedial facet fractures in patients with elbow injuries, with 15/18 having associated LCL injuries. Six patients had anteromedial facet fractures treated inadequately (nonsurgically or had failure of fixation), and all had inferior outcomes with varus subluxation of the elbow and radiographic elbow arthrosis. The remaining 12 had secure fixation of the anteromedial facet fracture and repair of other associated fractures/LCL injuries with all having good to excellent outcomes. Average flexion/extension arc was 116°, and average pronation/supination arc was 153° [14]. In a cadaveric biomechanical study, Pollock and coworkers evaluated the effect of anteromedial facet fracture size, location, LCL injury, repair on the coronal plane, and rotational stability of the elbow in comparison to the contralateral uninjured elbow. They found that as fracture subtype increased and size of fracture fragment increased, elbow instability increased. They also found that LCL deficiency in all fracture sizes with varus stress led to varus instability. However, in elbows with subtype 1, 2.5 mm fracture fragments with a repaired LCL demonstrated no significant difference in elbow kinematics in any position tested. Fracture fragments of 5 mm or greater of all subtypes demonstrated varus and internal rotation instability even with a repaired LCL. They recommend that all of these fractures are repaired in order to restore elbow stability [15]. Park and coworkers reviewed 11 patients with isolated anteromedial facet fractures and found 10/11 good/excellent outcomes with a treatment strategy based on fracture fragment size. The coronoid fractures were divided into subgroups utilizing the classification scheme devised by O'Driscoll in 2003. Their patients were treated as follows: subtype 1 fractures were treated with repair of the LCL alone, and subtype 2 and 3 fractures were treated with buttress plating and LCL repair. Average range of motion was 128°, and the average Mayo Elbow Performance Score was 89 [16, 17].

The coronoid fracture associated with terrible triad injuries is commonly transverse in orientation and located at the tip of the coronoid process [8]. Ring and coworkers reviewed the treatment and outcomes of 11 patients with fractures of the radial head and coronoid fracture. The coronoid was not fixed in any case, the radial head was repaired in 5/11, and the LCL was repaired in 3/11. Only 4/11 had excellent or good outcome scores (Broberg and Morrey), and all of these patients retained their radial head. After this review, the authors recommend repair of the LCL, repair or replacement of the radial head, and possibly repair of the coronoid [4]. Pugh and coworkers reviewed a standardized protocol for treatment of terrible triad injuries in 36 patients. The standardized treatment protocol includes in all cases repair or replacement of the radial head fracture, repair of the coronoid fracture if possible, and repair of the LCL and lateral capsule. In select cases of persistent instability, they additionally stabilized the MCL and/or placed a hinged external fixator. They found 28/36 good or excellent results with only one case of recurrent instability. Mean arc of elbow motion was 112° with a mean flexion contracture of 19°. Although there remains some debate in regard to terrible triad management, this standardized treatment protocol is currently considered by most as a reliable method to restore elbow stability and allow early range of motion [18]. The decision to fix the coronoid process fracture as well as the best method to fix the coronoid has been debated. Papatheodorou and associates reported 14 patients with terrible triad injuries treated with repair or replacement of the radial head fracture and repair of the LCL without coronoid fixation (all type 1 and 2 fractures) and found no cases of recurrent instability [19]. Hartzler and associates performed a cadaveric biomechanical study of six elbows with a coronoid fracture of 50% of the coronoid height. Coronal plane and rotational stability was then tested with and without coronoid fixation and with and without a radial head in place. The LCL was repaired in all cases. Fixation of the coronoid significantly improved varus and internal rotational stability in comparison to no fixation. The presence of the radial head was the predominant variable influencing valgus and external rotational stability, but fixation of the coronoid did provide a small but statistically significant improvement in valgus and external rotational stability [20]. Garrigues and associates evaluated fixation methods of the coronoid process in terrible triad injuries in 40 different patients. These patients were divided into two groups based on coronoid fixation method: suture anchors/screws ($n = 12$) and suture lasso fixation of the coronoid and anterior capsule ($n = 28$). The suture lasso technique provided significantly more intraoperative stability both before and after LCL repair as well as at late follow-up ($p < 0.05$) [21].

The LCL complex is often repaired as it adds to the stability of the unstable elbow. McKee and coworkers reviewed 61 cases of elbow instability with or without fracture and found that all patients had disruption of the LCL. The most common location of the LCL injury was avulsion off of the humeral origin (32/61). Disruption of the common extensor origin was seen in 66% of cases [22]. Forthman and coworkers reviewed 34 patients with complex elbow instability who were treated with repair or replacement of associated fractures and repair of the LCL without repair of the MCL. They found 74% good or excellent results and an average of 120° of ulnohumeral motion and 142° of forearm rotation. They concluded that the MCL does not routinely need to be repaired in cases of complex elbow instability [23].

Surgical Incision and Approaches

Numerous approaches have been described for reduction and stabilization of the three components of the complex elbow fracture dislocation. Most commonly utilized are the extensile posterior and combination of medial/lateral incisions. The choice of which incision to use is mostly academic and up to surgeon preference. While the posterior approach has been shown to cause less injury to subcutaneous nerves and subsequent neuroma formation [24], postoperative seroma formation has been well published. Further, there is literature to support treatment of the radial head from directly posterior through a transolecranon fracture, which may avoid the need for further lateral exposure in this particular fracture type [25]. In the situation where there is a separate medial coronoid fragment that requires fixation, the supine approach is often used to gain full access of the coronoid through the medial exposure, as this is often difficult in the prone/lateral position. An FCU-splitting approach has been demonstrated in a cadaver study to afford significantly more exposure to the coronoid and proximal ulnar shaft than an "over-the-top approach" [26]. Whichever surgical approach is chosen, it must provide for fixation of all necessary components of the injury simultaneously. In our specific case, there is proximal olecranon and metadiaphyseal fracture involvement which cannot be easily addressed with either lateral or medial incisions, so an extensile posterior approach was chosen.

External Fixation

Hinged external fixation of the elbow was originally described in 1975 by Volkov and Organesian [27]. In complex elbow instability cases, it is typically reserved for patients with residual instability after repair of the injured structures as noted by Pugh and associates [18]. Although hinged external fixation can provide additional stability in the complex elbow instability case, it is not without its own unique complications. In the largest series of hinged elbow fixators, Chueng and coworkers reviewed complications associated with 100 consecutive hinged elbow external fixators. They found a total of 25% complication rate with 15% superficial pin site infection/pin site skin tension, deep infection in 4%, pin loosening in 4%, purulent pin infection in 1%, and fixator malalignment in 1% [28]. Hinged external fixation traditionally utilizes an articular pin which is placed at the center of rotation for the elbow joint. However, inadequate placement of the axis of rotation pin on which the hinged fixator is built causes increased force required to move the elbow joint and leads to abnormal joint kinematics. This undue force on the joint and external fixator pins can lead to pin loosening, pin breakage, or joint subluxation/instability [29].

The application of the external fixator provides improved stability in the setting of the unstable elbow, but the kinematics of the elbow with a hinged fixator is not identical to the native elbow. Stavlas and associates performed a biomechanical cadaveric study with a hinged fixator and found that application of the hinged fixator significantly decreased elbow extension and forced the elbow into slight varus during the course of the flexion-extension arc [30].

Other authors recommend alternatives to traditional hinged external fixation for the persistently unstable elbow after fracture fixation and ligament repair in the complex elbow fracture dislocation. In hopes to avoid some of the articular pin-related complications, Bigazzi and coworkers developed an autocentering external fixator that has shown some promising early results with maintenance of reduction in 7/7 complex elbow pathology reconstructions [31]. Ring and coworkers compared the use of temporary ulnohumeral cross-pinning and cast application to hinged external fixation in the setting of persistent elbow instability. They found a higher rate of device-related complications in the external fixation group (7/19 patients) than in the cross-pinning group (1/10). The final Broberg and Morrey scores were identical, and there was no significant difference in final range of motion between the two groups [32].

Literature Inconsistencies

The current literature used as a guide for the treatment of elbow fracture dislocations is limited, as the majority of evidence is provided in the form of retrospective cohort studies. While the most optimal studies are large-scale prospective randomized trials which are the most ideal, this type of study is unlikely. It is important to address the potential fracture patterns and soft tissue injuries, and to assess the accuracy of fracture reduction and soft tissue repair while understanding the impact that the reduction of the articular surfaces involved will have on the functional outcomes. What is known is that a terrible triad injury has a substantially negative effect on function and quality of life.

Evidentiary Table and Selection of Treatment Method

The main studies related to the treatment of elbow fracture dislocations are included in Table 10.1 [5, 7, 9, 33–35]. Based on the literature, the authors recommend immediate open reduction and internal fixation with acute ligamentous repair.

Predicting Outcomes

When predicting outcomes of elbow surgical dislocation, treatment for each third of the triad should be evaluated. In regard to the radial head, the main question that needs to be answered is when the proper management is radial head excision, replacement, or ORIF. The previously mentioned study by Ring and associates found that

Table 10.1 Evidentiary table: A summary of the quality of evidence for treatment of elbow fracture dislocation

Author (year)	Description	Summary of results	Level of evidence
Ring et al. (2002) [5]	Retrospective study	Fifty-six patients with intra-articular fractures of the radial treated with open reduction and internal fixation. 4/15 Mason type 2 fractures of the radial head had an unsatisfactory result. 13/14 with Mason type 3 fractures had an unsatisfactory result concluding ORIF is best reserved for minimally comminuted fractures with three or fewer articular fragments	IV
Leigh et al. (2012) [7]	Retrospective study	Twenty-three patients with a terrible triad injury. Thirteen patients had ORIF of the radial head, while 11 had radial head replacement. Mean flexion was 135° (110–145), and mean extension was 8° (0–40). No patients had long-term instability. The only significant difference was that the radial head replacement group scored higher on the disabilities of the arm, shoulder, and hand assessment (DASH)	IV
Doornberg et al. (2004) [9]	Retrospective review	Review of 26 fracture dislocations of the elbow all with olecranon involvement. Five unsatisfactory results occurred in patients with inadequate coronoid fixation (3/5) and/or proximal synostosis (3/5). Thirteen patients with posterior dislocations and radial head fractures had worse clinical outcomes based upon American shoulder and elbow surgeon score, more limited ROM (than the patients with anterior dislocations) and more degenerative arthrosis	IV
Rhyou et al. (2014) [33]	(Correspondence) Meta-analysis re-updated (from 2010)	Reviewed 18 patients with O'Driscoll type 2 anteromedial facet fractures. Fractures which were 5 mm or smaller were treated with EUA if stable in varus, no surgical intervention was performed. If unstable, ORIF was performed. There were no significant differences in outcome scores (MEPS, VAS, DASH) or radiographic scores between coronoid fracture classification groups. Patients requiring UCL repair had significantly worse outcomes ($p = 0.03$)	I
Sun et al. (2016) [34]	Meta-analysis	Eight studies pooling 319 cases. Radial head arthroplasty had a significantly higher satisfaction rate, better elbow score (Broberg and Morrey) and MEPS, shorter operation time, lower incidence of nonunion or absorption, and internal fixation failure compared to ORIF. No significant differences in QuickDASH score and other complications	I
Zhang et al. (2016) [35]	Retrospective review	One hundred seven patients with operatively treated terrible triad injuries. 93% (100/107) treated with open fixation had no radiographic signs of subluxation or redislocation. Patients treated more than 2 weeks after injury might benefit from ancillary fixation to limit subluxation	IV

ORIF of the radial head should only be performed when the radial head is minimally comminuted and has three or fewer fragments [5]. Watters and coworkers performed a retrospective review of 39 patients (age 22–76) with terrible triad injuries whose radial head fracture was treated with either ORIF or radial head arthroplasty. Nine patients had ORIF and the other 30 had radial head arthroplasty. Indications for arthroplasty were more than three articular fragments, delamination of the articular cartilage, and comminution of the radial neck. All patients had repair of LUCL and the coronoid fracture. Furthermore, two had additional MCL repair, and three had an external fixator applied. At follow-up, there were no differences between groups in terms of ROM or elbow scores (DASH, MEPI). All arthroplasty patients had a stable elbow at final follow-up, whereas three of nine patients with ORIF were unstable ($p = 0.009$). Eleven arthroplasty patients (36%) had radiographic arthrosis compared to none in the ORIF group ($p = 0.04$). Twenty-eight percent of patients (seven arthroplasty, four ORIF) underwent reoperation for various reasons. For terrible triad injuries, radial head arthroplasty allows for early stability with comparable outcomes to ORIF, but long-term studies on arthrosis and effects of loosening are lacking [36]. When looking at the olecranon, proximal ulna/coronoid one surgeon-dependent predictor of outcome is the type of fixation used for open reduction and internal fixation. Ring and coworkers performed a retrospective case series on 17 patients with anterior transolecranon fracture dislocations, 14 of which had complex comminuted fractures of the proximal ulna. Similar to Doornberg's study, only 2 of the 17 had a radial head fracture, but 8 of the 17 had a large coronoid fragment that required separate fixation. All ulna fractures were treated surgically, 15 of the 17 were treated with plates (3 with 1/3 tubular or semitubular plates, others with 3.5 mm plates), and 2 were treated with tension band wires. Radial head fractures were treated with partial or complete excision. Two patients required early revision, both treated with 1/3 tubular plates that had to be revised to 3.5 mm plates. Average elbow flexion was 127° (range 100–140) and average flexion contracture was 14° (range 0–40). Only three patients lacked more than 20° of pronation or supination. There was no instability. This study shows the importance of concomitant coronoid and olecranon fixation and stabilization with at least a 3.5 mm plate, instead of 1/3 tubular plate or tension band fixation [10]. Another study further signifies the importance of implant type. Beingessner and associates described a fragment-specific approach to elbow fracture dislocations with associated ulnar fractures, particularly the Jupiter type IID subclassification of the Bado type II injury. This is described as a complex ulna fracture extending from the olecranon to the diaphysis [37]. They describe a specific stepwise approach for this injury in which the radial head is treated first, followed then by provisional fixation of the proximal ulna and coronoid. Of particular focus is fixation of the encountered anterior cortical fragment which is often part of the coronoid. They recommend using small 1ag screws and mini-fragmentary plates for initial stabilization and definitive fixation with a 3.5 LCDCP to resist bending. They specifically mention that a 1/3 tubular or reconstruction plate is not strong enough to resist the large bending forces of this injury [38]. Another question is: when is it necessary to repair the LCL complex? Rhyou and coworkers retrospectively reviewed 18 patients with O'Driscoll type 2 anteromedial facet fractures who were treated according to the senior authors' treatment strategy. All elbow instability patterns were classified by CT and 17/18 with MRI. Fractures which were 5 mm or smaller were treated with EUA, and if stable to varus stress in forearm pronation, no surgical intervention was performed. If unstable to varus stress, the LCL was repaired then retested for stability. In this study, after treatment, all cases were stable. In fractures larger than 6 mm, the fracture was treated with ORIF, and the elbow then underwent varus stress EUA. If the lateral joint demonstrated instability to varus stress, the LCL was repaired. If the elbow was stable to varus stress, the LCL was not repaired. Medial collateral ligament injuries were repaired if found during medial coronoid exposure. There were no significant differences in outcomes scores (MEPI, VAS, DASH) or radiographic scores between coronoid fracture classification groups. Patients requiring MCL repair had significantly worse outcomes ($p = 0.03$) [33].

It is well understood that all substantially sized bone fragments of the terrible triad should be replaced or repaired. The LCL often necessitates repair when there is residual instability after treatment of the bony complexes. It has also been shown that repair of the MCL is not necessary when the bony fragments and the LCL complex is stabilized [23].

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Distal Radius Fractures

11

Cameron T. Atkinson, Michelle S. Shen, Samuel A. Trenner, Philipp N. Streubel, and Jeffry T. Watson

WS: 55-Year-Old Male with Wrist Pain

Case Presentation

WS is a 55-year-old right-handed man who presents to the emergency department via self-transport complaining of severe wrist pain after a fall directly onto his outstretched right hand. He denies any loss of consciousness. On primary survey, he has a GCS of 15, has a patent airway, and is hemodynamically stable. Secondary survey reveals an obviously deformed right wrist. Past medical history is significant for insulin-dependent diabetes, for which he takes a combination of long-acting and regular insulin.

On physical examination, he demonstrates a normal radial pulse in the right upper extremity and obvious deformity of the right wrist. The compartments are soft, and radial, median, and ulnar nerves exhibit normal sensory and motor function.

Radiographs of the right wrist are demonstrated in Fig. 11.1a, b.

C. T. Atkinson
Arlington Orthopedic Associates, Arlington, TX, USA

M. S. Shen
Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA

S. A. Trenner
Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA

P. N. Streubel (✉)
Department of Orthopedic Surgery and Rehabilitation, University of Nebraska Medical Center, Omaha, NE, USA
e-mail: Philipp.streubel@unmc.edu

J. T. Watson
Colorado Springs Orthopedic Group, Colorado Springs, CO, USA

Interpretation of Clinical Presentation

The patient's findings and symptoms are consistent with an isolated intra-articular distal radius fracture. The low-energy mechanism makes it less likely that there are associated proximal injuries, but a full examination of the entire extremity, head, and neck should be completed. The radiographs demonstrate an extra-articular metaphyseal impaction, with nondisplaced sagittal split between the lunate, facet, and the scaphoid fossa. There is no coronal plane shear component evident on these radiographs.

Associated soft tissue injuries are frequent and often difficult to recognize on initial evaluation. In a retrospective review of 118 patients

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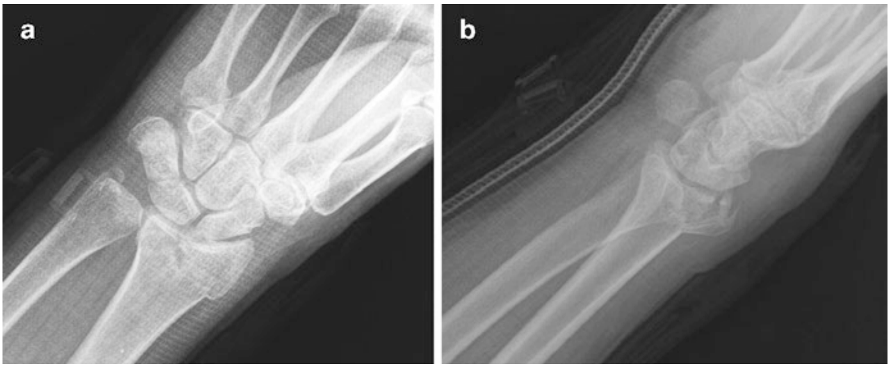

Fig. 11.1 (**a**) AP radiograph wrist (**b**) Lateral radiograph wrist

with operative distal radius fractures, Richards and coworkers demonstrated a 35% incidence of triangular fibrocartilage complex (TFCC) tear, a 21.5% incidence of scapholunate interosseous ligament (SLIL) tear, and a 6.7% incidence of lunotriquetral ligament (LTL) tear [1]. A review of 60 patients with intra-articular distal radius fractures by Geissler and coworkers demonstrated similar findings with incidences of 43% for acute TFCC, 38% for SLIL, and 15% for LTL tears [2]. Additionally, Ogawa and coworkers reviewed 89 patients who underwent surgical treatment by arthroscopy and found TFCC injury in 59%, SLIL injury in 54.5%, and LTL injury in 34.5% of cases [3]. The utility of more advanced imaging in the acute setting has not been studied extensively. In a case series presenting the findings of 21 patients with distal radius fractures, Spence and coworkers demonstrated six SLIL disruptions and two TFCC tears; five of the SLIL disruptions were apparent on plain X-ray [4]. The clinical significance of TFCC tears or SLIL disruptions identified solely on MRI or arthroscopy has not been established in the literature.

Bony injuries to consider include the uncommon concomitant scaphoid fracture and the more common ulnar styloid fracture. The clinical significance of ulnar styloid fractures in the setting of distal radius fractures is unclear. The attachment of the volar and dorsal distal radioulnar ligaments at the base of the ulnar styloid raises a theoretical concern for distal radioulnar joint instability with fracture of the ulnar styloid. In a retrospective review of 130 patients with distal radius fractures, May and coworkers demonstrated an 11% incidence of distal radioulnar joint (DRUJ) instability; the odds ratio of having DRUJ instability in the setting of a distal radius fracture with an ulnar styloid fracture was 30 [5]. Confounding these results is that less than half of the distal radius fractures were operatively treated either percutaneously or open. Malreduction of the sigmoid notch could also contribute to DRUJ instability. Conversely, in a prospective cohort of 138 patients with well-reduced distal radius fractures, Kim and colleagues demonstrated a 55% incidence of ulnar styloid fracture and found no differences in Disabilities of the Arm, Shoulder and Hand (DASH) score, modified Mayo wrist score, strength, or more importantly incidence of DRUJ instability when comparing those patients with styloid fracture and those without [6]. The degree of ulnar styloid fracture displacement was also found to have no effect on outcome. In another study examining outcomes after Kirschner wire fixation of distal radius fractures with and without associated ulnar styloid fractures, Zyluk and colleagues prospectively compared 70 patients. Thirty-five patients had an isolated distal radius fracture, and 35 had a distal radius fracture with an associated ulnar styloid fracture. All patients underwent percutaneous Kirschner wire fixation of the distal radius fracture, and the ulnar styloid fracture was left untreated. The stability of the distal radioulnar joint and the DASH scores were not significantly different between the two groups. Therefore, the investigators concluded that an unrepaired ulnar styloid fracture does not affect the outcome of a distal radius fracture when treated by a Kirschner wire fixation [7].

Traditionally, patients will undergo reduction of their fracture under hematoma block, regional anesthesia such as a Bier block, or conscious sedation and splinting. This patient would undergo hematoma block and sugar-tong splint application to allow for swelling during close outpatient follow-up.

Declaration of Specific Diagnosis

WS is a 55-year-old, right hand-dominant man who presents with an impacted intra-articular fracture of the distal radius.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals are focused on the following objectives:

1. Articular congruity
2. Radial alignment for maintenance of wrist kinematics
3. Early digital motion
4. Stability of distal radius
5. Stability of DRUJ

Treatment options are numerous and can be used in combination:

Nonoperative treatment:

1. Casting with or without manipulation

Operative treatment:

1. With or without arthroscopic-assisted reduction
2. Percutaneous fixation
3. External fixation:
   (a) Hinged versus nonhinged bridging
   (b) Bridging versus nonbridging
   (c) Dynamic versus static
4. Internal fixation:
   (a) Volar locked plating
   (b) Dorsal plating
   (c) Intramedullary nailing
   (d) Spanning internal fixation

Evaluation of the Literature

In order to identify relevant publications on distal radius fractures, Medline and PubMed searches were performed. Keywords included the following: "distal radius fracture." Subheadings included "conservative treatment" and "surgical treatment." This search identified 2122 abstracts that were reviewed. From this search, 215 articles were read, and reference lists were reviewed. The search was limited from 1975 to 2011. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

As mentioned above, there are a variety of treatment options available for distal radius fractures. They can be used alone and in combination, making analysis of the evidence for each more difficult.

Nonoperative Treatment

Cast treatment with or without closed reduction has long been considered a viable option for treatment of distal radius fractures. In a case-control study including 90 patients with a mean age of 65, Egol compared nonoperative treatment against external fixation with percutaneous pinning or open reduction and internal fixation (ORIF) of displaced distal radius fractures. While the patients in the operative treatment group had better radiographic outcomes at all time points, there were marginal but statistically significant differences in both supination (3° more in the nonoperative group) and grip strength (5 kg greater strength in the operative group). Most importantly, however, there was no difference in DASH scores, indicating equal functional outcomes as measured by this instrument [8].

Azzopardi and colleagues published a randomized trial of 57 patients over the age of 60 with distal radius fractures to cast treatment or percutaneous pinning with casting. Outcomes included overall health and well-being by SF-36, pain, radiographic outcomes, and grip strength. There were improved radiographic outcomes with percutaneous pinning but no statistically significant differences in SF-36 scores, pain, wrist supination, pronation, dorsiflexion, or palmar flexion [9].

Arora and colleagues retrospectively reviewed 114 patients older than 70 years with unstable distal radius fractures that underwent ORIF or closed treatment despite loss of reduction. At mean follow-up of greater than 4 years, there were better radiographic outcomes in the ORIF group but no difference in DASH, patient-related wrist evaluation (PRWE), or visual analog scale (VAS) pain scores. Those treated in a cast surprisingly had 5° more wrist flexion and less pain, both statistically significant findings. In this retrospective study, better radiographic outcomes did not translate into better pain or functional outcomes [10].

Ju and colleagues completed a meta-analysis to determine the best treatment option of distal radius fractures in persons 65 years of age or older. Eight studies with 440 surgical patients and 449 nonsurgical patients were identified. There were no significant differences in DASH scores, VAS pain score, grip strength, wrist extension, pronation, supination, or ulnar deviation between the two groups. The authors concluded that in regard to treatment options of distal radius fractures in the elderly, nonsurgical and surgical methods produce similar outcomes [11].

Similarly Roumen and associates prospectively studied 93 elderly patients with distal radius fractures. Of the 93 patients, approximately half were successfully treated closed with one manipulation; those that failed reduction were randomized to either repeat closed reduction with external fixation or nonoperative treatment without another reduction attempt. Using the Lidstrom classification [12] and de Bruijn score [13], there was no correlation between functional outcome and the anatomic result. In fact, there was better patient satisfaction among those patients who failed initial reduction and were treated nonoperatively versus those treated with an external fixator [14].

The following question then arises: Do the commonly applied radiographic parameters for acceptable alignment correlate with outcome in all patients? Gartland and Werley related outcome to volar tilt, radial inclination, and ulnar variance [15]. Knirk and Jupiter published on the outcomes of young patients with distal radius fractures and noted poorer long-term radiographic results with greater than 2 mm of intra-articular incongruity. In their often-cited review of 43 patients with a mean age of 27.6 years at a mean follow-up of 6.7 years, residual articular incongruity was found to have the strongest correlation with posttraumatic arthritis and a less favorable outcome by the Gartland and Werley score [16]. Knirk and Jupiter's classic study however had no interobserver or intraobserver agreement, had questionable radiographic evaluations, and lacked validated functional outcome measures [17]. Grewal and MacDermid prospectively followed 297 patients with extra-articular distal radius fractures for 12 months, with PRWE and DASH scores as their primary outcome measures. With 72% follow-up, fracture malalignment was significantly associated with decreased PWRE and DASH scores in those patients under 65 years old but was not associated with a change in functional scores. Even when accepting up to 30° of dorsal angulation and 5 mm of positive ulnar variance, patients over 65 years old still had no significant difference in their function scores between those with acceptable and unacceptable alignment [18].

In a younger population, Karnezis and associates compared clinical and radiographic outcomes in 30 patients with unstable distal radius fractures. In contrast to Grewal's cohort, their average age was 46 years old. All underwent closed reduction and percutaneous pin fixation. At 1 year, the presence of an articular step-off of 1 mm or more adversely affected wrist extension and PRWE scores. Similarly, radial shortening and loss of palmar tilt were associated with more pain as measured by the PRWE pain sub-score. Radiographic outcomes in this younger population have an effect on outcomes as early as 1 year [19].

Brogren and associates examined 123 distal radius fractures looking at arm-related disability during the first 2 years. In this study, all patients were treated with closed reduction and casting, external fixation, or percutaneous pin fixation. With malunion defined as ulnar variance of 1 mm or more and dorsal tilt greater than 10°, it was found that mean change in DASH scores was significantly worse for patients with malunion [20].

Trumble et al. retrospectively reviewed 43 patients with displaced intra-articular distal radius fractures with a mean age of 37 and found, through the use of a nonvalidated outcome system, that functional outcome correlated with the degree of displacement [21]. As suggested above, ultimate articular congruity and radial alignment have less impact in lower demand, geriatric patients, making nonoperative treatment an attractive option in this population. In a younger population, however, unstable distal radius fractures with alignment that cannot be maintained nonoperatively may be better served with operative treatment.

Operative Treatment

Arthroscopic-Assisted Reduction

If operative treatment is undertaken, an assessment of articular congruity and other injuries can be done with arthroscopy of the radiocarpal joint. Varitimidis and associates randomized 40 patients to arthroscopy- and fluoroscopy-assisted reduction or standard fluoroscopy-assisted reduction alone, prior to external fixation and percutaneous pinning of distal radius fractures. Patients who underwent arthroscopy- and fluoroscopy-assisted reduction had a mean DASH score of 12, as opposed to a score of 25 in the group that underwent fluoroscopy-assisted reduction alone. Clinically significant differences were not seen at 1 or 2 years. Using arthroscopy, they also identified 9 SLIL, 4 LTL, and 12 TFCC tears; all of the SLIL injuries were reduced and percutaneously pinned, while the LTL and TFCC injuries were all debrided arthroscopically [22].

In examining fragment-specific fixation for distal radius fractures, Thiart and associates compared the use of fluoroscopy and arthroscopy. All 44 patients were treated with fragment-specific fixation while using fluoroscopy. After the fragment-specific fixation was complete, but before the completion of the surgical intervention, arthroscopy was used to determine all gap and step-off distances and any other wrist injuries. Thirty-seven out of 44 patients showed no gap distances during arthroscopy. The authors concluded that intra-articular distal radius fractures can successfully be treated with fragment-specific fixation with the use of fluoroscopy. Because almost all of the gap and step-off distances were reduced without arthroscopy, they concluded that the added benefit of arthroscopy is limited in these cases [23].

In a case-control study, Ruch and associates compared 15 patients who had undergone arthroscopy-assisted reduction with an equal number who had undergone fluoroscopy-assisted reduction. All patients underwent reduction, external fixation, and percutaneous pinning; the mean age across both groups was 39. At 12-month follow-up, those patients who underwent arthroscopy-assisted reduction had 15° better supination, 8° better extension, and 19° better flexion. Five SLIL tears, four LTL tears, and ten TFCC tears were identified in the arthroscopic group. Seven of the TFCC tears with 50% or more detachment from the ulna were repaired. Despite the identification of multiple other injuries, there was no statistically significant difference in DASH scores between the two groups [24].

Percutaneous and External Fixation

Among the several means to maintain reduction of operative distal radius fractures, percutaneous pin fixation is among the least invasive and can be used in combination with other methods, including external fixation. In a prospective, randomized study, Harley and coworkers compared percutaneous pinning and casting against external fixation and supplementary percutaneous pins. The average age of patients in this study was 42; the authors were only able to follow up 66% of patients at 1 year. There were no significant differences in range of motion, grip strength, or patient health as measured by SF-36 or DASH scores at 1 year [25].

Hutchinson and coworkers randomized 90 patients to either percutaneous pin or external fixation. Across both groups the average age was

65, and they were followed for 2 years to be assessed for range of motion, strength, nonvalidated questionnaires meant to evaluate disability as well as satisfaction, and radiographic outcomes. At final follow-up, there was no difference in range of motion, degenerative changes, or strength with high patient satisfaction in both groups. The authors do, however, note that external fixators are more expensive [26].

In a randomized trial, Kreder and coworkers compared bridging external fixation with optional percutaneous pins versus closed reduction and casting in 113 patients with extra-articular fractures with an average age of 53. Seventy-five percent of patients were available at 2 years for follow-up, and 35% of patients in the external fixator group underwent supplemental percutaneous pinning. Though treatment with external fixation provided better average Musculoskeletal Functional Assessment (MFA) upper limb scores, Jebsen Taylor functional scores, and strength, these differences did not reach statistical significance due to a lack of power [27]. In another randomized trial, Kreder and colleagues assigned 175 patients with intra-articular fractures to undergo indirect reduction and fixation with an external fixator, percutaneous pins, or a combination versus ORIF through either a dorsal or a volar approach using nonlocked plates. The mean age of patients was approximately 40 years in each group. With 66% follow-up at 2 years, the indirect reduction group had better mean grip strength by 10 pounds and a better mean MFA upper limb score by 6 points utilizing ANOVA which provides a global comparison of the two groups over the entire study period. At 6 months, there was a 12-point difference favoring indirect reduction in MFA upper limb score. At 1 and 2 years, however, there was no significant difference between indirect reduction and ORIF [28].

Egol and coworkers published a randomized study comparing 38 patients treated with bridging external fixation with 30 patients treated with percutaneous pins and volar locked plating. The average age across both groups was 51 years. The internal fixation group had significantly better wrist pronation at 6 months and 1 year and better wrist extension at 6 months. No differences were found in DASH score, motion, or complication rate at any time point. Only two patients in the external fixation group required a repeat operation, whereas five patients in the ORIF group required another operation, typically for plate removal [29].

A systematic review by Kasapinova and coworkers compared ORIF with percutaneous fixation. At 3, 6, and 12 months, no significant difference was seen in patient-rated wrist evaluation (PRWE), grip strength, or radiographic outcomes. Interestingly, at 3 and 6 months postoperatively, the ORIF group had better DASH scores, but no significant difference was seen at 12 months [30].

Various methods of external fixation have also been compared. Atroshi and colleagues compared bridging with nonbridging external fixation by randomizing 19 distal radius fracture patients with a mean age of 71 years to each treatment. Operative time was 10 min longer for nonbridging external fixation, but there were no significant differences in ROM, grip strength, or DASH scores at 1-year follow-up [31]. Krishnan and colleagues also randomized patients with an average age of 56 to nonbridging or bridging external fixation. At 6 months and 1 year, there were no significant differences in pain as measured by VAS pain score, ROM, grip strength, radiographic outcomes, or ability to complete activities of daily living (ADLs) [32]. In a meta-analysis of 905 patients from 6 different cohort studies, Gu and colleagues compared the effectiveness of bridging external fixation versus nonbridging external fixation. They found that the nonbridging patients had a higher risk of pin-tract infection, higher degree of flexion, rupture of the extensor pollicis longus, and nerve injury as compared to the bridging patients. However, there were no significant differences in other complications or the recovery of function between the two groups [33].

One known and worrisome complication of bridging external fixation of distal radius fractures is postoperative stiffness of the wrist. There are designs meant to combat this problem. Sommerkamp and colleagues randomized a group of patients to either static bridging external fixation or hinged bridging external fixation, which allows early wrist motion. In both groups, the external fixators were kept in place for 10 weeks, with the hinged fixator group beginning ROM exercises at 2 weeks. Despite having 8 more weeks to work on ROM, the hinged fixator group had no better motion than that of the static bridging fixator group. In fact, at 1 year, the static bridging fixation group had slightly more flexion (59° vs. 52°) and radial deviation (21° vs. 15°) than the hinged bridging fixation group, though the clinical significance of these differences is minimal. There was also a significant loss of radial length in the hinged fixator group as compared to the static fixator group (4 vs. 1 mm) [34]. Hove and colleagues randomized 70 patients to a more conventional bridging external fixator or treatment with a dynamic external fixator of their design-in-use in Norway. This unique external fixation device uses compression and distraction forces, not a hinge, to maintain traction while still permitting wrist motion. The average age of patients in this study was 54 years, and they were followed for a year. While there were small but statistically significant 1-year differences in ROM favoring dynamic bridging external fixation, the mean wrist extension in the dynamic group was 11° greater than in the static group and was the only significant finding. There was no difference in DASH scores or pain between groups [35]. At this point, there is little support for the application of a hinged over a static external fixation device.

Internal Fixation

Just as there are multiple external fixation methods available for the treatment of distal radius fractures, there are also multiple internal fixation methods and approaches at the surgeon's disposal. Leung and colleagues compared external fixation with plate fixation via a dorsal, volar, or combined approach in their randomized study of 144 intra-articular distal radius fractures to internal versus external fixation. The mean patient age was 42 years, and there were no patients older than 60. Of the 70 fractures in the ORIF group, 40 (57%) were fixed via a volar approach, 12 (17%) via a dorsal approach, and 18 (26%) via a combined approach. At 2 years follow-up, patients treated with ORIF had the following results by the Gartland and Werley scoring system: 67% excellent, 30% good, and 3% fair. By comparison, there were 39% excellent, 55% good, and 6% fair in the external fixation group, a significant difference ($p = 0.04$). Complications were similar between the two groups [36].

Dorsal plating has been and continues to be a popular method, but reports of persistent pain, tendon rupture, and other complications have raised concern. However, this may be due to device selection. Rozental and colleagues retrospectively reviewed 28 patients who had dorsally displaced distal radius fractures that were treated with dorsal plating. With an average age of 42 years, 19 patients were stabilized with the original version Synthes (Paoli, PA) Pi plate, while 9 had a low-profile plate. At minimum 1-year follow-up, 7 of 19 (37%) patients who were internally fixed with a Pi plate underwent hardware removal for extensor tendon irritation and tenosynovitis, while 1 patient had an extensor digitorum communis tendon rupture directly over the prominent Pi plate. This is compared to no reoperations in the low-profile plate group [37]. A subsequent version of the Pi plate offered tapered contours in an effort to reduce soft tissue irritation. Simic and colleagues published a retrospective cohort study focusing on functional outcomes after ORIF of distal radius fractures with low-profile plates. Sixty fractures in 59 patients with a mean age of 55 years were treated with a low-profile plate; average follow-up was 24 months. Only one patient required hardware removal for dorsal wrist pain. That patient had no signs of tendon irritation at time of plate removal, and removal of the plate did not relieve the patient's symptoms. Thirty-one patients had an excellent outcome, and 19 had a good outcome by the scoring system of Gartland and Werley. The mean DASH score for the entire cohort was 11.9 [38].

Several studies have compared dorsal plating with volar plating. Rein and colleagues retrospectively compared dorsal and volar plating in 29 patients with an average age of 49 years with either a locked or nonlocked plate. At an average follow-up of 22 months, the dorsal plate group had a mean DASH score of 17 compared to a mean DASH of 14 in the volar plate group—an insignificant difference. No statistically significant differences were found between the two groups with regard to pain, ROM, or radiographic outcomes. Seven complications were noted in the dorsal plate group, including two cases of extensor tendon irritation and two cases of fracture displacement. This is contrasted with one case of fracture displacement and one case of complex regional pain syndrome in the volar plate group [39]. In a retrospective review of 34 patients with an average age of 47 years with operatively treated intra-articular distal radius fractures, Ruch and Papadonikolakis compared the results of nonlocked volar and dorsal plating. At a mean follow-up of 21 months, there were no significant differences in range of motion, DASH scores, or grip strength. The small difference in Gartland and Werley score (2.2 vs. 4.4, volar and dorsal, respectively) is of little clinical significance [40]. In a retrospective study of 71 patients, Kumar and colleagues compared complication rates between low-profile dorsal plating versus volar plating. The dorsal plating group had 89% excellent/good restoration and 11% fair restoration. In comparison, the volar group had 96% excellent/good restoration and 4% fair restoration. The patient-related wrist evaluation scores were comparable between the two groups. The authors concluded that the outcomes of low-profile dorsal versus volar plating were comparable [41].

The growing trend in North America is operative treatment of displaced distal radius fractures with a volar locked plate [42, 43]. Wei and colleagues randomized 46 patients with an average age of 58 years to external fixation or internal fixation with either a volar locked plate or a locked radial column plate. At 3 months, patients treated with a volar locked plate had significantly better DASH scores compared to those treated with external fixation (mean 7 vs. 29, $p = 0.028$) and to those treated with a locked radial column plate (mean 7 vs. 28, $p = 0.027$). By 6 months, this difference disappeared. At 1 year, however, the volar locked plate produced better DASH scores than the locked radial column plate (mean 4 vs. 18, $p = 0.025$). There were no significant differences in range of motion after 6 weeks of follow-up [44].

Rozental and colleagues prospectively compared volar locked plating with closed reduction and percutaneous pinning by way of a randomized trial of 45 patients with an average age of 51 years. At 6 and 9 weeks, there was significantly better range of motion and DASH scores in the locked plate group through 12 weeks of follow-up (mean 11 for plate vs. 26 for CRPP, $p = 0.01$). With 90% follow-up at 1 year, however, there were no significant differences in DASH scores, ROM, patient satisfaction, or radiographic outcomes [45].

Other internal fixation options include fragment-specific fixation and nail-plate hybrid constructs. Available data on these methods of fixation show results similar to those seen in other studies [46], but there are limited comparative studies available. Abramo and colleagues prospectively randomized 50 patients, mean age of 48, to either open reduction with fragment-specific fixation or closed reduction with external fixation treatment arms. At 1 year, there was significantly greater grip strength (90% of contralateral side in ORIF vs. 78% in external fixation groups, respectively, $p = 0.03$) and forearm rotation (149° vs. 136° in ORIF vs. external fixation groups, respectively, $p = 0.03$). There was, however, no difference in DASH scores at any time point, including at 1 year. Ten malunions (five requiring operative revision) occurred in the external fixation group compared to three malunions with only one revision in the ORIF group [47]. Biomechanical studies have shown nail-plate hybrid constructs to provide significant resistance to torsional and bending forces [48, 49], but limited clinical data support the use of these novel implants. Rampoldi and colleagues reported on the clinical outcomes of 46 patients with distal radius fractures that had been treated with the dorsal nail plate. With an average follow-up of 11 months, the average final DASH score was 6 (range 0–20). All fractures went on to union but with loss of initial reduction in two patients. Two patients had intraoperative extensor pollicis longus tendon partial lacerations [50].

Another internal fixation method described is the spanning internal fixator. Used in high-energy fractures of the distal radius with a high degree of comminution where maintenance of length is of concern, it theoretically reduces the risks of pin-tract complications seen with external fixation while providing for distraction across the fracture. Ruch and colleagues published the results of 22 patients with an average age of 54 years who sustained comminuted distal radius fractures and were treated with 3.5-mm plate spanning the radiocarpal joint. Kirschner wires were used to supplement the fixation as needed. In this series, all the fractures healed at an average time of 110 days with a mean palmar tilt of 4.6°. Average DASH scores were 33.8 at 6 months, 15.4 at 1 year, and 11.5 at final average follow-up of 24.8 months. One concern with this technique is postoperative stiffness; at 1 year, flexion and extension averaged 57° and 65°, respectively [51]. In a larger series, Hanel and colleagues reported the results of 62 patients with an average age of 47.8 years who had distal radius fractures treated with a spanning internal fixator supplemented with Kirschner wires. All fractures went on to union with at minimum neutral palmar tilt, greater than 5° of radial inclination, and within 5 mm of ulnar neutral. Forty-one of the 54 (76%) patients who had been working preoperatively returned to their previous level of employment. The only complications in this series were seen in a patient who chose to keep his plate in place for 19 months so that he could continue with work activities. His plate broke 16 months after implantation and was removed when it became symptomatic. During plate removal, he sustained a ruptured extensor carpi radialis longus tendon; this was treated with tenodesis to the extensor carpi radialis brevis tendon [52]. A spanning internal fixation plate can be effective in these severe rare fractures.

In a retrospective study of 62 patients between the ages of 50 and 70 years old, Lee and coworkers compared the outcomes of volar locking plating and percutaneous Kirschner wiring for management of displaced Colles type distal radius fractures. They found that wrist flexion, extension, and ulnar deviation were all significantly better in the volar locking plating group as compared to the percutaneous Kirschner wiring group. The authors concluded that both groups had high union rate and low complication rate, but that better functional results were achieved in the volar locking plating group [53]. Additionally, Zong and coworkers performed a meta-analysis of 875 patients to compare volar locking plate versus percutaneous Kirschner wires for dorsally displaced distal radius fractures. At the 1-year follow-up, those patients who underwent volar locking plate fixation had statistically better DASH scores and reduced incidence of total postoperative complications as compared to those who underwent percutaneous Kirschner wire fixation. The volar locking plate fixation group also had significantly better grip strength and range of wrist flexion and supination in the 6-month postoperative period as compared to the percutaneous Kirschner wire group. However, the authors acknowledge that there are still insufficient data to prove that one method is definitively better than the other [54].

Evidentiary Table and Selection of Treatment Method

The key studies influencing treatment of WS are noted in Table 11.1 [29, 30, 36, 44, 45]. The authors feel that he is best served with operative treatment of this fracture. His age of 55 should be considered on an individual basis, as some in that age group are clearly more active than others. If he were "physiologically older" with a low-demand lifestyle, nonoperative management would be a viable option. The available literature suggests that, among the various treatment methods, volar locked plating provides adequate stability to maintain an anatomic reduction for this impacted, intra-articular distal radius fracture. Volar locked plating can be used predictably to restore articular congruity, maintain radial alignment, and create a stable distal radius. The best data available demonstrate that volar locked plating does provide for better

Table 11.1 Evidentiary table: A summary of the quality of evidence for volar locked plating of displaced distal radius fractures

Author (year)	Description	Summary of results	Level of evidence
Wei et al. (2009) [44]	Randomized trial	46 patients with distal radius fractures randomized to external fixation, a radial column plate, or a volar locked plate demonstrated better DASH scores at 3 months with volar plating	I
Leung et al. (2008) [36]	Randomized trial	144 patients with intra-articular distal radius fractures underwent plate fixation vs. external fixation with percutaneous pins with better wrist scores for plate fixation group	I
Rozental et al. (2009) [45]	Randomized trial	45 patients with distal radius fractures randomized to closed reduction, percutaneous pinning vs. volar locked plating with plated group demonstrating better ROM, strength, and DASH scores at early follow-up but no difference at 1 year	I
Egol et al. (2008) [29]	Randomized trial	77 patients with distal radius fractures treated with volar locked plate vs. external fixation with percutaneous pins, with minimal early improvement in ROM in plate group and no significant differences at 1 year	I
Kasapinova et al. (2014) [30]	Systematic review	10 studies with 647 distal radius fractures compared ORIF with percutaneous fixation. At 3, 6, and 12 months, no significant difference in patient-rated wrist evaluation (PRWE), grip strength, or radiographic outcomes. At 3 and 6 months postoperatively, the ORIF group had better DASH scores, but no significant difference was seen at 12 months	I

early motion and patient-reported outcomes but shows little long-term clinical benefit compared to external fixation or percutaneous pinning. With long-term outcomes among treatment methods being similar, the choice of volar locked plating is based on its low complication rate and better early outcomes.

It should be noted that, despite the current enthusiasm for volar locked plating, there is little if any evidence to suggest that it is superior to dorsal plating for management of impacted distal radius fractures. In the authors' opinion, application is a little easier, and patients seem to have an easier time with early digital mobilization with the volar approach. However, potential ease of application should not supplant attention to plate position and length of subchondral screws or pegs. Placement of the plate too far distally over the watershed line has resulted in flexor tendon irritation and rupture, whereas excessive screw/peg length has been shown to create similar problems for dorsal tendons. While this is a common rationale for volar locked plating, there is little long-term clinical difference between it and external fixation.

Predicting Outcomes

The long-term results of patients treated with volar locked plating have not been rigorously studied. Gruber and coworkers prospectively followed 54 patients with distal radius fractures treated with volar locked plating for 6 years. Fifty-one of 56 (94%) patients had a good or excellent result according to the Gartland and Werley score. The mean DASH score across the entire cohort at 6 years was 13 compared to a score of 5 at 2 years. Radiographic signs of arthritis, but not loss of reduction, were associated with significantly worse outcomes by SF-36 and DASH scores. Of note, there was a significant difference on subgroup analysis at 6 years, with those patients less than 60 years of age having a mean DASH score of 4 and those 60 years or older with a mean DASH score of 20 [55]. Whether this difference is due to baseline differences, such as sex, between these two subgroups is unclear, but the difference between the younger active population and the elderly population is again underscored. More long-term prospective studies are needed to examine long-term outcomes after volar locked plating of distal radius fractures.

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Part IV

Acetabular, Hip, and Pelvic Trauma

12 Acetabular Fractures in the Elderly

John C. Weinlein, Edward A. Perez, Matthew I. Rudloff, and James L. Guyton

GV: 76-Year-Old Man with Left Hip Pain

Case Presentation

GV is a 76-year-old man who complains of severe left hip pain after a fall from standing height. He was transferred to the emergency department by EMS. On presentation, he demonstrates a GCS of 15 and denies any loss of consciousness. On primary survey, his airway is patent, and he is hemodynamically stable. On secondary survey, he demonstrates severe pain with passive range of the left hip. His secondary survey is otherwise negative.

His medical history is notable for coronary artery disease but is otherwise negative. He takes no medications and has no allergies. His surgical history is remarkable for multiple abdominal surgeries secondary to persistent left inguinal hernia. He is a household ambulator and denies previous hip pain.

On physical examination of his left lower extremity, his neurovascular status is intact, and he has full strength throughout. His physical exam is otherwise unremarkable.

J. C. Weinlein (✉) · E. A. Perez · M. I. Rudloff
J. L. Guyton
Regional One Health, University of Tennessee – Campbell Clinic, Memphis, TN, USA
e-mail: jweinlein@campbellclinic.com

Radiographs and CT of the pelvis are shown in Figs. 12.1a–c and 12.2a–d.

Interpretation of Clinical Presentation

Based on his clinical and radiographic examinations, the patient is diagnosed with a left acetabular fracture. Imaging reveals a left acetabular fracture that is actually a transitional pattern between an anterior column–posterior hemitransverse (ACPHT) and an associated both-column (BC) acetabular fracture. The plain films alone reveal an anterior column–posterior hemitransverse; however, the CT scan reveals a nondisplaced fracture line resulting in an associated both-column acetabular fracture [1]. The fracture has significant displacement of the anterior column, a separate quadrilateral plate component, and superomedial dome impaction. These three radiographic features have been shown to be more common in elderly patients than in younger patients with acetabular fractures [2]. Importantly, there is no medial subluxation of the femoral head, and partial secondary congruence is present. The patient also does not appear to have a significant lesion of his femoral head on CT. The mechanism of injury is an important consideration because it may be indicative of a pathologic process, in this case osteopenic bone. The patient's history is notable for coronary artery disease, but he currently is not taking any medica-

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Fig. 12.1 (**a**) AP radiograph pelvis. (**b**) Iliac oblique radiograph pelvis. (**c**) Obturator oblique radiograph pelvis

tions. He is a household ambulator and does not have underlying hip pain. The medicine service would be consulted for risk stratification, as this information is important in counseling the patient on treatment options. The patient's mental status needs to be assessed and considered in developing a treatment plan. We feel that placement of a traction pin affords this patient no benefit, regardless of the ultimate treatment decision.

Declaration of Specific Diagnosis

GV is a 76-year-old male who presents with a left acetabular fracture after a ground-level fall. The fracture is a transitional pattern between an anterior column–posterior hemitransverse and an associated both-column that functionally acts as an associated both-column acetabular fracture.

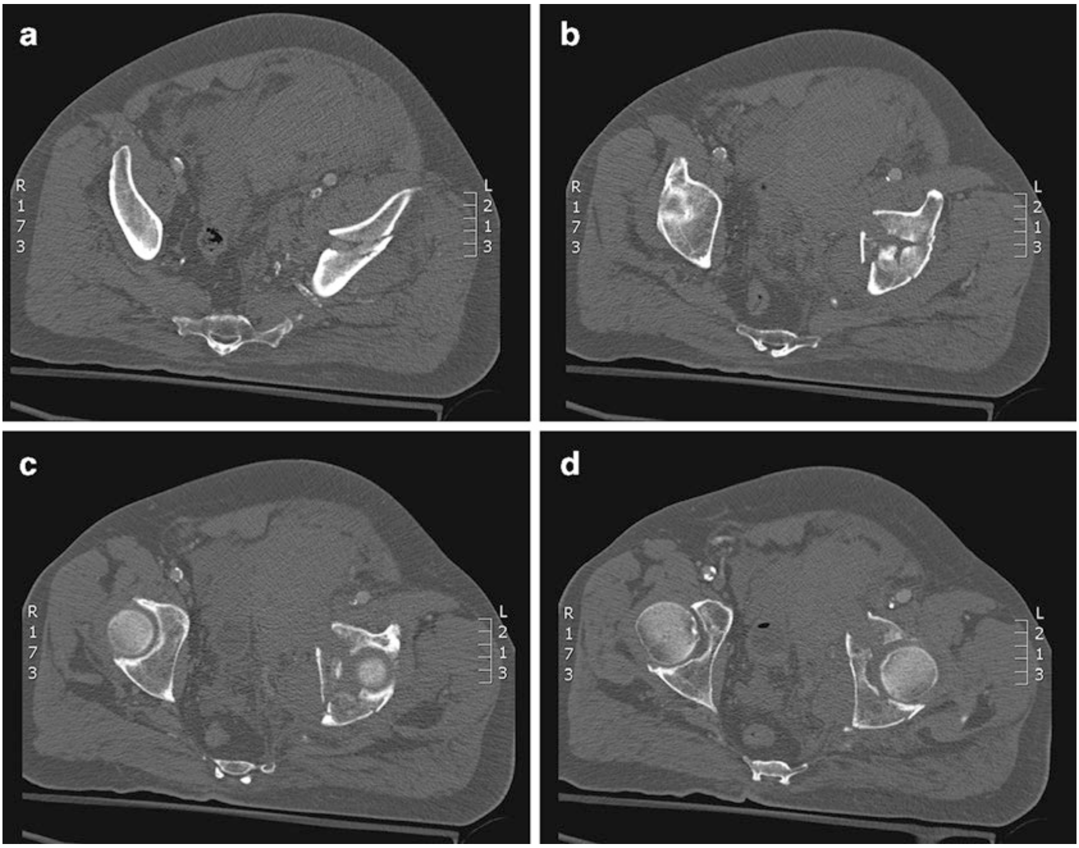

Fig. 12.2 (**a**–**d**) Axial CT pelvis

Brainstorming: What Are the Treatment Goals and Options?

The goals of treatment in GV are to restore him as close as possible to his preinjury functional status while minimizing his morbidity. Considerations in treatment include pain control, mobilization, and future hip function.

Treatment options include the following:

Nonoperative treatment:

1. Successful return to function with secondary congruence of the acetabulum
2. Initial conservative treatment with delayed THA, as clinically necessary

Operative treatment:

1. Open reduction and internal fixation (ORIF)
2. Limited open reduction and percutaneous fixation
3. ORIF (or percutaneous fixation) combined with acute THA

Evaluation of the Literature

To identify relevant data on the treatment of acetabular fractures in elderly patients, PubMed searches with the following keywords were used: "acetabular fracture." The search identified 810 abstracts that were reviewed. These abstracts were reviewed and pertinent articles were read. The reference section of each pertinent article read was also reviewed, and additional relevant articles were included. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

Multiple treatment options exist for this 76-year-old man with an acetabular fracture as a result of a ground-level fall. The following sections explore each of these treatment options. The highest quality and relevant articles discussing each treatment option are included. Unfortunately, high-quality prospective studies comparing different treatment options in geriatric both-column acetabular fractures are lacking. Many different outcome scores are used in the reporting of outcome data for the different treatment options. These different outcome scores can make direct comparison quite difficult. The utility of the Merle d'Aubigne score, which has been used extensively in the literature, has been called into question due to ceiling effects [3]. The ceiling effect implies a nonnormal distribution of scores with a higher than expected percentage of good to excellent results. Also, many of the functional outcomes measures commonly used in the literature include physical exam findings which can be difficult to obtain in geriatric patients who often live a significant distance from the tertiary referral center [4].

Treatment Options

The majority of the literature concerning operative versus nonoperative treatment of acetabular fractures involves the five elementary fracture patterns and the four associated fracture patterns other than the associated both-column acetabular fracture [5]. Typically operative indications include displaced acetabular fractures that involve the weight-bearing dome (roof arcs <45° or a CT subchondral roof arc <10 mm) or cause femoral head incongruity with the weight-bearing dome and unstable posterior wall acetabular fractures [6]. The criteria for nonoperative treatment of associated both-column acetabular fractures are distinct from the nine other fracture patterns. The term "secondary congruence," initially described by Letournel, applies only to associated both-column acetabular fractures. Secondary congruence implies that with central displacement of the femoral head, the columns rotate away from one another but maintain contact with the femoral head. The presence or absence of secondary congruence dictates nonoperative versus operative treatment. Unfortunately, the term "secondary congruence" can be ambiguous. Various authors describing the level of secondary congruence have applied adjectives such as "reasonable," "acceptable," and "imperfect." Letournel himself in describing his results of nonoperatively treated both-column acetabular fractures identified three cases that did not have "complete secondary congruence" but had "partial congruence." Also, the operative indications that have been defined and are well accepted in the younger population may not be completely generalizable to the geriatric acetabular fracture population.

Conservative/Nonoperative Treatment

One of the most frequently cited articles advocating against nonoperative treatment of acetabular fractures in elderly patients is that of Spencer published in 1989 [7]. This study was a retrospective review of 25 patients with unilateral acetabular fractures managed without surgery. Of the 23 patients available for follow-up between 9 and 52 months, 7 (30%) had unacceptable functional results. Those with unacceptable functional results included six patients who were "able to walk but only with severe pain." Sixteen patients (70%) were "able to return to previous level of activity." Adequate follow-up radiographs were not available to allow the authors to adequately classify the fractures and therefore make any comparisons between nonoperative treatments for different fracture patterns. Most of the patients in this study were osteopenic, and the mechanism of injury was a ground-level fall. At least some of these patients were treated with traction, as the study indicates that nine patients had traction removed before 6 weeks. The percentage of the overall patient population that was treated in traction was not clearly stated. Three patients had diagnosed femoral head fractures, with at least two being associated with poor results. An even higher percentage of patients may have had femoral head injuries, but most patients had inadequate radiographs. An interesting finding was the frequency of late displacement (5 of 14) in patients with osteopenia. Some of these patients had significant late displacement even when their initial AP pelvic radiograph showed minimal or no displacement. Surprisingly, none of the patients in this series experienced complications related to prolonged recumbency.

The long-term results of conservative management of displaced acetabular fractures have been examined in India [8]. Thirty-two patients with displaced (>3 mm) acetabular fractures involving the weight-bearing dome and treated conservatively were retrospectively reviewed. Of these 32 patients, 2 patients had an associated both-column acetabular fracture, and no patient had an anterior column–posterior hemitransverse acetabular fracture. The average age of the patients was 42 years (the oldest patient in the series was 66 years), and the mean follow-up was 4.2 years. The reasons for nonoperative management were multiple, but in only one case was "severe osteoporosis" given as the reason for nonoperative management. Nonoperative management consisted of closed reduction and application of longitudinal and/or lateral traction. Traction was used for a mean of 7.7 weeks (range 6–12 weeks). Adequate fracture reduction (<3 mm) was possible in 56% of patients. Fifteen of 18 patients with an adequate fracture reduction had excellent or good clinical results. An adequate fracture reduction was possible in only 14% of patients with gross initial displacement of more than 20 mm and in only 40% of patients with central fracture dislocations. The authors reported several pin-tract infections but only two cases of gluteal sores secondary to conservative treatment with traction; there was no mention of pulmonary complications secondary to prolonged recumbency. The patients in this study were all younger than GV.

Interestingly, the patients treated nonoperatively in Letournel and Judet's large series were initially treated with 5 weeks of bed rest [9]. The authors believed traction to be unnecessary in the conservative treatment of acetabular fractures. Osteopenia of the innominate bone was considered the "most important contraindication to operative treatment." Seventeen both-column fractures were treated conservatively, with 14 fractures displaying secondary congruence and 3 fractures demonstrating partial congruence. Fifteen patients had follow-up that averaged 4.3 years; 11 of 13 patients with secondary congruence had very good clinical results. In terms of the two patients with partial congruence, one had a very good clinical result and the other had a good clinical result. There were 18 other patients, excluding patients with both-column and posterior wall acetabular fractures, who had normal head–roof congruency on AP pelvic radiographs and a minimum of 2 years of follow-up. Of these, 13 patients had very good clinical results and 2 demonstrated good clinical results when displaying congruency on AP pelvic radiographs.

In a more recent study, Ryan and coworkers showed no differences in functional outcomes between a cohort of geriatric patients who underwent nonoperative treatment of an acetabular fracture meeting operative criteria and a cohort of operatively treated geriatric patients from the same institution [10]. WOMAC scores as well as mortality rates were similar between the two cohorts. Rate of conversion to THA was 28% in the operatively managed cohort versus 15% in the nonoperatively managed cohort.

Unlike fractures of the proximal femur, nonoperative treatment of acetabular fractures does not result in increased mortality. Gary and coworkers reported an overall 1 year mortality of 16% in 454 acetabular fractures in patients greater than 60 years of age [11]. Treatment included ORIF (174), nonoperative (164), percutaneous (80), and acute THA (36). After adjusting for comorbidities, no differences were found in mortality among different treatments and more specifically among different treatments in those greater than 70. Of note is the fact that ground-level fall was the most common mechanism (51.3%) and BC acetabular fracture was the most common resultant fracture type (24%), both consistent with GV. Bible and coworkers also recently reported a low 1-year mortality rate (8.1%) in isolated acetabular fractures at a single center [12]. The authors did not find a statistically significant difference in mortality in isolated acetabular fractures treated nonoperatively versus operatively. Nonoperatively treated patients were 4.6 years older but spent 2.6 days less in the hospital.

A recent study showed the significant variation in treatment of geriatric acetabular fractures [13]. The treatment of displaced acetabular fractures in patients ≥60 years was evaluated at 15 level 1 trauma centers across the USA. Forty-nine percent of patients had acetabular fractures resulting in an incongruent hip. Only 60% of patients were treated operatively. Eighty-eight percent of operatively treated patients were treated with ORIF (vs 12% with THA). Based on the heterogeneity in treatment, the authors concluded that "to date, there are no treatment guidelines for treating acetabular fractures in older adults."

The consensus of the literature reviewed appears to be that some patients have a satisfactory result after conservative treatment of a displaced acetabular fracture, but there are no clear guidelines as to determining which elderly patients or fracture characteristics in elderly patients portend a good result following nonoperative management of these injuries.

Operative Treatment

Open Reduction Internal Fixation

Operative treatment of acetabular fractures has not been as successful in older patients as in younger patients. In Matta's series of 259 patients operated on within 3 weeks of injury, patient age was associated with accuracy of reduction [14]. Anatomic reductions, defined as 0–1 mm of displacement, were achieved in 78% of patients younger than 40 years old but in only 57% of patients older than 40 years; 81% of patients younger than 40 years of age had excellent or good clinical results, while 68% of those older than 40 years had excellent or good clinical results. These clinical results are based on a modified Merle d'Aubigne score including pain, ambulatory ability, and hip range of motion. When quality of reduction was controlled, the clinical results were not significantly different between age groups. Overall, 77% of the associated both-column acetabular fractures in this series had excellent or good results.

The percentage of patients with excellent or very good results decreased with age in the series of Letournel and Judet as well [9]. Results deteriorated with age, with the exception of patients in the 70- to 79-year age range and in the one patient over 80. Because there were only ten patients who were 70 years of age or older, the authors cautioned against abandoning ORIF based purely on chronologic age. Overall, 82% of the associated both-column acetabular fractures in this series had excellent, very good, or good results according to the Merle d'Aubigne score.

Anglen and coworkers, in a retrospective review of 48 patients over 60 years of age with surgically treated displaced acetabular fractures, identified a specific radiographic finding predictive of failure [15]. The "gull sign" represents displaced superomedial dome impaction. Of the ten patients in their series who demonstrated a "gull sign," all had either inadequate reduction, early loss of reduction, or early loss of superomedial joint space with recurrent subluxation. These ten patients also had medial displacement of the femoral head, a finding that is not consistent with GV's radiographs.

Helfet and colleagues reported successful outcomes in 18 patients who were at least 60 years old and who had ORIF of displaced acetabular fractures [16]. Indications for surgical management included more than 5 mm of displacement involving the weight-bearing dome and subluxation as measured on AP and Judet views of the pelvis. All surgeries were performed by a single, experienced pelvic and acetabular surgeon using a single nonextensile surgical approach based on the preoperative imaging. All patients were independent ambulators in good health preoperatively. The mechanism of injury was a fall in half of the patients, although there was some difficulty in distinguishing between ground-level falls and falls from greater heights.

Seventeen of 18 patients who were followed for at least 2 years had an average Harris hip score (HHS) of 90. Fifteen of the 18 patients had excellent or good results, and only 1 patient had a poor result based on HHS.

A more recent series with the same experienced surgeon (Helfet) [17] included 149 patients at least 55 years of age (mean age 67 years) who had management of displaced acetabular fractures with ORIF (140 patients) or with combined ORIF/acute THA (9 patients). Ninety-three patients met all inclusion criteria including at least 2-year follow-up. The mechanism of injury was a ground-level fall in 47 of the 93 patients. At an average 5-year follow-up, 31% of patients had required delayed THA. Fracture reduction was found to be predictive of late THA; however, the "gull sign" was not predictive of a worse clinical outcome. Compared to patients who had delayed THA and patients who did not ultimately require THA, patients with acute THA had higher scores on the physical component of the SF-36, but there were no other differences among the groups in any of the other functional outcome scores.

Jeffcoat and colleagues reported the utilization of a limited ilioinguinal approach in the treatment of acetabular fractures in an older patient population [18]. The limited ilioinguinal approach included only the lateral two windows of the standard ilioinguinal approach. The authors compared the results of this limited ilioinguinal approach to the standard ilioinguinal approach. The limited ilioinguinal approach resulted in significantly decreased operative time (207 vs 273 min) and blood loss (572 vs 904 cc). The quality of reduction and functional outcomes did not differ between groups. Overall, 26.8% of patients underwent subsequent THA at a mean of 33 months.

Archdeacon and colleagues reported on the utilization of anterior approaches to the acetabulum in the treatment of geriatric acetabular fractures with associated protrusio [19]. Anterior approaches included modified ilioinguinal [20] (31 patients), modified Stoppa [21] (5 patients), and standard ilioinguinal (2 patients). Fractures primarily included ACPHT (56%) and both-column (23%), and 82% of fractures were the result of a fall from standing height. Mean operative time was 238 min, and median EBL was 500 cc (one case did have a 9000 cc EBL). Twenty of 38 patients had an anatomic reduction based on plain films; however 21/31 patients had a poor reduction based on CT scans. Despite a high percentage of patients without anatomic reductions, only 19% of patients underwent subsequent THA at a mean of 18 months.

O'Toole and colleagues reported a 28% incidence of conversion to THA after ORIF of acetabular fracture in patients ≥60 years of age [22]. Conversion occurred at an average of 2.5 years after ORIF. The mean follow-up in this series was 4.4 years. Thirty-six percent of acetabular fractures that had a posterior wall (PW) component went on to subsequent THA versus only 17% of patients without PW component.

Laflamme and colleagues described a series of 21 patients older than 60 years of age (average age 64 years) or with documented osteoporosis in whom acetabular fractures were treated surgically [23]. The acetabular fractures involved the anterior column and quadrilateral plate with displacement or protrusion of more than 1 cm. Fractures were treated with the modified Stoppa approach (buttress plating of the quadrilateral surface). The most common method of buttressing the quadrilateral plate was the use of a reconstruction plate contoured to fit the infrapectineal region inside the true pelvis. The mean Harris hip score was 86.2, with 71% of patients having excellent or good results. The "gull sign" was found to be predictive of a lower quality of initial reduction and the need for THA.

Laflamme and colleagues more recently described a technique for direct reduction of superomedial dome impaction in geriatric acetabular fractures [24]. Nine patients were treated with this technique, whereas three patients were treated nonoperatively and three others with acute THA. Modified Stoppa or modified ilioinguinal approaches were utilized for ORIF. Reconstruction began with reducing medial or central subluxation of the femoral head. The impacted dome fragment was then reduced to the femoral head under direct vision through the Stoppa window after rotating the displaced quadrilateral surface fragment. The reduced impacted fragment was then supported with graft. The quadrilateral fragment was then reduced and stabilized with infrapectineal plating. Reduction was within 3 mm in 7/9 (78%) patients; however 33% of patients underwent subsequent THA at a mean 2.8-year follow-up. Qureshi and colleagues also described the utility of infrapectineal plating in fractures with associated displacement of the quadrilateral surface [25].

Casstevens and associates reported a similar technique to that of Laflamme for reducing superomedial dome impaction [26]. The authors report eight ACPHT and two BC fractures resulting primarily from a ground-level fall (9/10). The authors initially describe attempting to work through displaced anterior column or quadrilateral surface fracture lines to access impaction. However, they add a description of an osteotomy of the anterior column/ilium when access is still problematic. The authors report the results of ten patients utilizing these techniques of which an osteotomy was used in three cases. The modified Stoppa approach was used in all cases and the median EBL was 1270 cc. Ninety-day mortality was 20%. Of the remaining eight patients, only one patient had undergone THA at 6 months after injury. Radiographic follow-up was available for six patients at 1 year, and four patients were graded as "excellent" according to the criteria of Matta.

If ORIF were selected for treatment of GV's fracture, the operative approaches that could be used would include the ilioinguinal (standard, limited, or modified) and the modified Stoppa. An ilioinguinal or modified Stoppa approach certainly could be complicated by GV's history of multiple abdominal surgeries secondary to a persistent left inguinal hernia. We believe given the evidence presented that ORIF of GV's fracture has a very high likelihood of failure.

Limited Open Reduction and Percutaneous Fixation

Few reports have been published describing percutaneous fixation or limited open reduction and percutaneous fixation of acetabular fractures. Starr and associates introduced the concept of limited open reduction and percutaneous fixation of displaced acetabular fractures in 2001 [27]. The authors' initial report included a subset of 13 elderly patients (mean age 66 years) with displaced acetabular fractures. All 13 patients had radiographic findings that the authors felt to be predictive of posttraumatic arthrosis: femoral head fracture, comminution of the weight-bearing dome or posterior wall fracture, and medial displacement and comminution of the quadrilateral surface in the setting of osteopenia. Goals of fixation included mobilization, decreased pain, decreased further displacement, and improvement of the technical ease of a future THA. Maximal displacement at the joint was reduced from 10 mm preoperatively to 3 mm postoperatively. Eleven patients were available for follow-up at an average of 12 months. These elderly patients had a mean Harris hip score of 85 although five had undergone THA. This initial report did not specify exactly which fracture patterns were treated.

Gary and associates reported a series of 79 patients 60 years of age or older who had percutaneous reduction and fixation of the acetabulum [28]. Twenty-eight fractures (35%) in this study were both-column acetabular fractures, similar to that of GV. Reductions were carried out through stab incisions and small iliac wing approaches with the use of elevators, pushers, and specialized reduction clamps. Once reduction was obtained, fractures were stabilized with percutaneously placed 6.5-mm or 7.3-mm cannulated screws. Twenty patients (25%) ultimately required THA with a mean time to THA of 1.41 years; only five patients (6%) had a loss of reduction after percutaneous fixation. A subsequent report of this same patient population revealed that 30.5% of patients had undergone THA at an average of 2.4 years [29]. Functional outcomes scores were available for 35 patients at an average of 6.8 years after index percutaneous fixation. 13/35 patients initially had both-column acetabular fractures. No statistically significant differences were found in functional outcomes when this cohort was compared to population norms for patients greater than 60. Average HHS was 76.8 for patients maintaining native hip and 83.3 for those that had undergone THA. The authors then compared the HHS score for those that had undergone THA to those previously reported in the literature of acute THA for acetabular fracture. The authors found no difference in functional outcomes when comparing to two studies [30, 31] and improved outcomes when comparing to one other study [32].

In the series reported by Mouhsine and associates, 21 patients with a mean age of 81 years had nondisplaced or minimally displaced acetabular fractures that were treated with percutaneous fixation [33]. Weight-bearing as tolerated was allowed at 4 weeks. Eighteen patients were available for follow-up at a minimum of 24 months. The fractures in 14 patients were the result of a ground-level fall, and the fracture types included transverse, both-column, and T-type patterns. No complications were reported with percutaneous screw insertion. At a mean follow-up of 3.5 years, 17 of 18 patients had excellent or good clinical outcomes. No evidence of fracture displacement was seen.

Limited open reduction and percutaneous fixation are, at least theoretically, attractive in a subgroup of elderly patients with acetabular fractures. However, we are not aware of any objective data showing improved mobilization and decreased pain after percutaneous fixation of acetabular fractures. We have limited experience with this technique.

ORIF/Acute Total Hip Arthroplasty

Some authors have argued that ORIF, with subsequent THA at the same operative setting, may be in the best interest of a certain subset of patients, including patients with acetabular fractures that have been correlated with poor outcomes after ORIF alone. Mears and Velyvis reported on 57 patients who had acute THA after stabilization of the acetabular columns [30]. The mean age of the patients was 69 years, and the mean follow-up was 8.1 years (range 2–12 years). Indications for arthroplasty included intra-articular comminution, abrasive loss of the articular surface or impaction of the femoral head, and significant impaction involving the weight-bearing dome. Columns were stabilized with several techniques including lag screws, braided cables, and multiple screws placed through the acetabular component. Patients were allowed to bear weight as tolerated at 6 weeks. The average medial migration of the acetabular component was 3 mm, and the average vertical migration was 2 mm. No evidence of late loosening was apparent. Significant polyethylene wear was found in 16% of patients, but none of the acetabular components were revised for this reason. The mean HHS was 89, and 79% of patients had excellent or good clinical outcomes. However, only 4 of the 57 fractures in this series were associated both-column acetabular fractures.

Mouhsine and associates described the use of techniques similar to those outlined by Mears and Velyvis (cable fixation and acute THA) in 18 patients with a mean age of 76 years [34]. Weight-bearing was initiated early, and migration of the acetabular component was similar to that reported by Mears and Velyvis. Seventeen of the 18 patients had excellent or good clinical outcomes at a mean of 3 years.

Herscovici and associates described different methods of stabilization of the acetabular fracture before acute THA [32]. Their series of 22 patients with a mean age of 75.3 years all had significant osteoarthritis, significant osteopenia, or fracture of the femoral head. In 3 patients, an ilioinguinal approach was used for fixation of the acetabular fracture before repositioning for THA, and in 19 patients, a Kocher–Langenbeck approach was used for fixation of the acetabular fracture followed by THA through the same approach. Fifty percent of patients had a cemented acetabular component placed. Weight-bearing was not allowed for 3 months postoperatively. Mean follow-up was 29.4 months. In the three patients with an ilioinguinal approach, surgical times averaged 427 min, blood loss averaged 2225 cc, and transfusions averaged 5 units of PRBCs. Overall, five patients required revisions. Harris hip scores at final follow-up averaged 78.6 in the 19 patients who had 1 surgical approach (Kocher–Langenbeck) and 69.3 in the 3 patients who had 2 surgical approaches.

Boraiah and associates reported another small series of 21 patients (mean age 71 years) who had fixation of an acetabular fracture followed by THA (uncemented acetabular component) through a Kocher–Langenbeck approach [31]. Patients were allowed to begin weight-bearing as tolerated at 3 months. One patient required a revision for acetabular component failure at 3 weeks. While there was an average of 1.2 mm of medial migration and 1.3 mm of vertical migration of the acetabular component, there was no evidence of loosening. Harris hip scores averaged 88, with 81% of patients having excellent or good scores.

Lin and coworkers reported 33 patients with an average follow-up of 5.6 years (range 1–14.3 years) who underwent acute THA for acetabular fracture [4]. Twenty-eight of 33 patients were treated with isolated Kocher–Langenbeck (KL) approach and 4 patients underwent initial ilioinguinal approach followed by KL approach. Four patients did not require internal fixation prior to THA. The most frequent reason for acute THA was "severity of the acetabular fracture" (58%). Uncemented acetabular components, with additional screws in 85% of cases, were utilized in all but one case. The 90-day mortality was 10%. Ninety-three percent of patients had a good or excellent functional outcome based on the Oxford hip score. The authors reported 94% survivorship at an average 5.6-year follow-up. Two patients had failure of acetabular fixation within the first 3 months, and one of these two occurred in a press-fit cup without additional screws. A limitation of this study is that only 36% of patients had radiographic follow-up beyond 1 year.

Enocson and coworkers reported 15 patients with an average age of 76 years who underwent acute THA for acetabular fracture utilizing a Burch-Schneider reinforcement ring [35]. The average age of these patients was 76 years and all were independent ambulators preoperatively. 14/15 patients had either anterior column (10) or anterior column–posterior hemitransverse (4) acetabular fractures. Of note is that both-column acetabular fractures were not included. No attempt was made to reduce fracture displacement prior to ring placement, and the average blood loss was 665 cc. The authors reported 20% 1-year mortality. HHS averaged 88 at 4-year follow-up, and there was no evidence of loosening of the ring in the 11 patients still alive.

The Levine approach has been described for ORIF/acute THA [36]. This approach allows stabilization of acetabular fractures with mainly anterior column involvement followed by acute THA through the same exposure. In a series of ten patients with a mean age of 61 years, there was no evidence of acetabular component migration at a mean follow-up of 36 months. The mean clinical outcomes as measured by the Merle d'Aubigne score were good (16) with a range of fair (13) to excellent (18). The mean estimated blood loss was 1060 cc, and the mean operative time was 3 h. No patients required revision THA within this follow-up period. The authors reported that they have not used this technique for both-column acetabular fractures because of concerns about nonunion.

Chakravarty and colleagues reported the results of acute THA for acetabular fracture after performing percutaneous column fixation [37]. They report the results of 19 patients with an average follow-up of 22 months. Nine patients sustained either ACPHT or BC acetabular fractures. Column fixation was performed with 6.5-mm cannulated screws in the supine position prior to proceeding with THA in the lateral position. All acetabular components were cementless. Mean operative time was 231 min and mean blood loss was 700 cc. The authors did report 42% incidence of medical or surgical complications and concluded by stating that the use of this technique "in older patients, injured in falls from a standing height, should be questioned." The 1-year mortality was 26% and 58% of patients had died within 38 months. Of note is the fact that no patients in this study required revision for component loosening.

Because of the characteristics of GV's fracture, performing primary THA in conjunction with ORIF would require the Levine approach or two approaches: an ilioinguinal or modified Stoppa approach followed by a Kocher–Langenbeck approach. Based on the small number of patients in the series of Herscovici and coworkers who required two approaches, GV's operative time and blood loss would be expected to be excessive with two approaches. While the authors initially describing the Levine approach were concerned about nonunion in using this approach with associated both-column acetabular fractures [21], this concern should not be as much of an issue in this case as the fracture is a transitional pattern with a nondisplaced posterior column. A posterior column screw or screws could be placed through this approach. ORIF with acute THA, even utilizing the Levine approach, likely would be associated with significant blood loss and possibly a prolonged operative time. We would discuss the risks and benefits to the patient, but we feel ORIF with acute THA is not the best choice for GV given the available evidence.

Delayed THA

Total hip arthroplasty is a solution for posttraumatic arthritis of the hip following acetabular fracture, which can occur after nonoperative treatment or after open reduction and internal fixation (or limited open reduction and percutaneous fixation). Weber and coworkers reported 66 patients who had THA for posttraumatic arthritis after ORIF of an acetabular fracture [38]. Forty-four of the 66 patients had cemented acetabular components. At a mean follow-up of 9.6 years, 17 patients had required revision THA and 16 revisions had been done because of aseptic loosening (including aseptic loosening in 9 acetabular components). None of the cementless acetabular components were revised or showed evidence of loosening. The presence of large residual segmental and cavitary defects was associated with aseptic loosening. A recent follow-up report of this same cohort revealed an overall 57% acetabular survivorship at a mean of 20 years, compared to 87% survivorship at a mean of 10 years [39]. At a mean of 20 years, 71% of acetabular components were free from revision for aseptic acetabular loosening, compared to 87% at a mean of 10 years. There was no difference in aseptic acetabular loosening between cemented (69% survivorship) and uncemented (75% survivorship) acetabular components at this long-term follow-up.

Bellabarba and coworkers reported their experience with cementless acetabular components for posttraumatic arthritis [40]. Thirty patients with an average age of 51 years were followed for an average of 63 months (minimum of 2 years). Fifteen patients were initially treated conservatively, and 15 were initially treated with ORIF. Only nine patients (30%) did require bone grafting for acetabular defects. The mean Harris hip score at final follow-up was 88; 90% had excellent or good results. One patient required revision because of aseptic loosening. This patient was initially treated with ORIF and subsequently developed an acetabular nonunion. Patients who had ORIF of their acetabular fractures had longer operative times and more blood loss at surgery but less frequently required bone grafting than patients who were initially managed with conservative treatment. There were no significant differences between the two groups with regard to HHS or postoperative complications.

Romness and Lewallen reported their experience with THA in 53 patients (mean age 56 years) who developed posttraumatic arthritis after acetabular fractures treated with a variety of techniques [41]. The authors found that age at the time of THA was an important predictor of need for revision. Patients younger than 60 years had a 17.2% incidence of revision, while those older than 60 years had a 7.7% incidence of revision.

Ranawat and coworkers used cementless acetabular components for THA in 32 patients who had acetabular fractures treated with ORIF (24 fractures) or without ORIF (8 fractures) [42]. Six patients required revision during the 5-year follow-up period. Overall, the mean HHS was 82. There was no significant difference in the HHS between patients initially treated with ORIF and those not treated with ORIF. Over half of the patients (17) required revision THA. Nonanatomic restoration of the hip center was predictive of revision surgery; however, no difference was found between initial ORIF and non-ORIF management in predisposition to nonanatomic restoration of the hip center. History of infection was also predictive of revision surgery. Six patients (21%) initially treated with ORIF had a history of infection prior to THA. Interestingly, three patients (38%) initially treated without ORIF had a history of infection prior to THA. There was one nonunion of a fracture that was initially treated with ORIF.

Morison and coworkers recently compared THA after acetabular fracture to a matched cohort of THA for osteoarthritis (OA) or avascular necrosis (AVN). Not surprisingly, THA performed after acetabular fracture had more complications than THA performed for OA or AVN [43]. THA after acetabular fracture had greater incidence of infection (7% vs 0%) and dislocation (11% vs 3%), than THA for OA/AVN. Seventy-four patients with previous acetabular fracture underwent THA at a median of 4 years after fracture, all with cementless acetabular components (4/74 had hybrid THA with cemented femoral component). 58/74 patients had initially been treated with ORIF (16/74 patients had been treated nonoperatively). Overall 10-year survivorship was 70% in THA after acetabular fracture (versus 90% in THA for OA/AVN). Patients older than 60 had an 83% 10-year survival of THA after acetabular fracture. While not reaching statistical significance ($p = 0.15$), the revision rate for THA after ORIF of an acetabular fracture was 36% versus 17% after nonoperative treatment of an acetabular fracture. Of note is the fact that no acute THA was performed in this study.

Schnaser and coworkers reported lower functional outcome scores in patients undergoing THA after acetabular fracture vs primary THA. Patients undergoing THA after acetabular fracture had worse functional outcome scores reflected by the musculoskeletal functional assessment and Harris hip score [44]. A limitation of this study includes a small number of patients (17) being converted to THA after acetabular fracture. Of these 17 patients, 13 had been treated with ORIF, 3 nonoperatively, and 1 with acute THA.

If GV develops symptomatic posttraumatic arthritis after nonoperative or operative treatment, he should be treated with THA using a cementless acetabular component with screws. He would be more likely to require bone grafting at THA if initially treated nonoperatively; however, he would likely have a shorter operative time and experience less blood loss. Interestingly, nonunion was noted at THA only in patients who had previous ORIF in the series of Ranawat and colleagues. Based upon GV's age, his risk of requiring revision THA should be fairly low.

See Table 12.1 for evidentiary table that gives a summary of the quality of evidence for THA for posttraumatic arthritis after acetabular fracture [38–40, 42, 43].

Selection of Treatment Method

Based upon the available literature, we believe that initial nonoperative treatment is in this patient's best interest.

Definitive Treatment Plan

The patient should be evaluated by a physical therapist to determine if he has the overall strength and endurance to attempt to mobilize, touch-down weight-bearing (TDWB), on the left lower extremity. He should remain TDWB until union of the fracture. Radiographs should be obtained after mobilization to confirm that partial secondary congruence is maintained and that there has been no medial subluxation of the femoral head. Adequate pain control in the first few days after injury is very important. We would make sure that the patient was able to mobilize. If the patient were not able to mobilize, then we would proceed down a different path, likely ORIF/acute THA.

Predicting Long-Term Outcomes

If partial secondary congruence is maintained, the patient has a chance to have a reasonable functional outcome without further surgery. If

Table 12.1 Evidentiary table: A summary of the quality of evidence for THA for posttraumatic arthritis after acetabular fracture

Author (year)	Description	Summary of results	Level of evidence
Bellabarba et al. (2001) [40]	Retrospective study	30 patients with posttraumatic arthritis treated with THA (uncemented acetabular component). 90% of patients had excellent or good functional results on the Harris hip score. No significant differences in functional outcome found between patients initially treated conservatively versus ORIF. Average f/u was 63 months	IV
Ranawat et al. (2009) [42]	Retrospective study	24 patients with posttraumatic arthritis treated with THA (uncemented acetabular component). 81% of patients had excellent or good functional results on the Harris hip score. No significant differences found between patients initially treated with or without ORIF	IV
Weber et al. (1998) [38]	Retrospective study	66 patients with posttraumatic arthritis treated with THA (44/66 had cemented acetabular components). At ~10 year f/u, 9 cemented acetabular components had been revised, whereas 0 of the uncemented acetabular components had been revised	IV
Von Roth et al. (2015) [39]	Retrospective study	25/66 of above patients available at ~20 year f/u. 71% acetabular survivorship free from aseptic acetabular loosening. 57% acetabular survivorship free from revision for any reason	IV
Morison et al. (2016) [43]	Retrospective study	74 patients that had undergone THA (cementless acetabular components) for posttraumatic arthritis were compared to matched cohort of patients undergoing THA for OA/AVN. 10-year survivorship was 70% with THA for posttraumatic arthritis (83% in patients older than 60); 36% revision rate after initial ORIF compared to 17% revision rate after initial nonoperative treatment ($p = 0.15$)	III

he does develop symptomatic posttraumatic arthritis, delayed THA offers a reliable solution and can be done at a time when the patient's fracture has healed and his general health is optimized. Secondary congruence certainly is important, although even perfect secondary congruence as created in the laboratory is associated with increased peak pressures in the acetabular dome [45]. While GV does not have perfect secondary congruence, he does have partial secondary congruence. Displacement appears better tolerated in elderly patients, as illustrated in a recent study showing that the quality of reduction on CT was not correlated with functional outcomes in an elderly population with operatively treated acetabular fractures [46]. With GV's age and level of activity, he may do well functionally for several years. If he does require THA, the literature suggests that with a cementless acetabular component, GV should expect good to excellent results.

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13 Pelvic Ring Injury I

Rita E. Baumgartner, Damien G. Billow, and Steven A. Olson

DP: A 43-Year-Old Male with Pelvic Ring Injury

Case Presentation

DP is a 43-year-old man who complains of right pelvic pain after being a restrained passenger in a motor vehicle accident. He is transferred to the emergency department via EMS. On presentation, he demonstrates a GCS of 15 and denies any loss of consciousness. On primary survey, his airway is patent, and he is hemodynamically stable. On secondary survey, he demonstrates some pain with manipulation of his pelvis on the right side. His secondary survey is otherwise negative.

His past medical history is negative. He takes no medications and has no allergies.

On physical examination, his pelvis is stable to stress examination. He has pain with posterior palpation of his pelvis. He is neurologically intact.

Radiographs and CT of the pelvis are demonstrated in Figs. 13.1a–c and 13.2a, b.

R. E. Baumgartner (✉) · S. A. Olson
Department of Orthopaedic Surgery, Duke University Medical Center, Durham, NC, USA
e-mail: rita.baumgartner@dm.duke.edu

D. G. Billow
Department of Orthopedics, Cleveland Clinic, Cleveland, OH, USA

Interpretation of Clinical Presentation

The patient's findings and symptoms are consistent with an isolated pelvic ring injury with fractures of the right superior and inferior rami and complete Zone I fracture of the right sacrum. The sacroiliac joint appears to be maintained. Due to the high-energy mechanism required to sustain this injury, one should routinely consider clearance of the head, chest, and abdomen by the emergency department or trauma service to assure no subtle or occult injuries. Lefaivre and colleagues reviewed 100 consecutive lateral compression pelvic fractures. 98 of the 100 had a sacral fracture, of which 47 were complete fractures. They found that complete sacral fractures were associated with significantly higher abdominal AIS scores as compared to incomplete fractures. Additionally, they found a trend toward higher average ISS scores in those with complete fractures [1]. In a retrospective review of 362 patients with blunt pelvic fractures, the presence of a sacral fracture was shown to have an increased relative risk of 1.6 of having an associated bladder injury [2].

It is required to note vital signs and hemodynamic stability. In a review of 343 patients with major pelvic ring disruptions, Dalal and colleagues demonstrated a relationship between injury mechanism and associated injuries and volume resuscitation requirements. Lateral

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Fig. 13.1 (**a**) AP radiograph of the pelvis. (**b**) Inlet radiograph of the pelvis. (**c**) Outlet radiograph of the pelvis

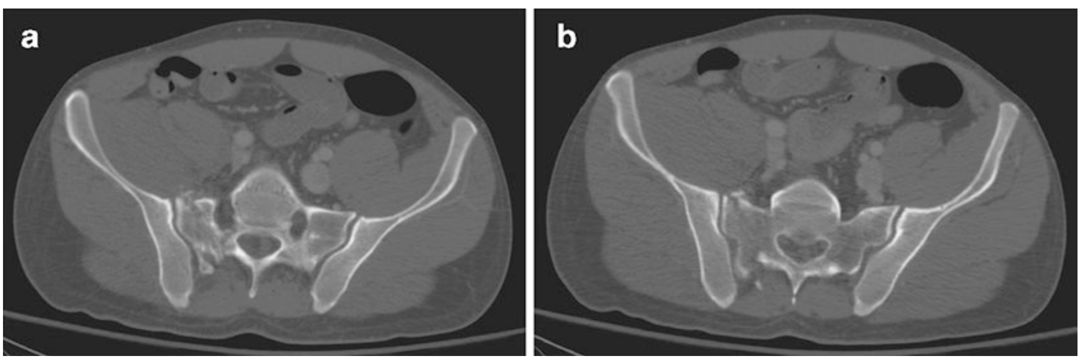

Fig. 13.2 (**a**, **b**) Axial CT of the pelvis

compression pelvic fractures were associated with brain injury in up to 50% of patients in addition to increased lung, spleen, liver, and bladder injuries. This fracture pattern can lead to a significant degree of hemodynamic instability in up to 40% of patients [3]. In an evaluation of 210 consecutive patients with high-energy pelvic ring injuries, those with lateral compression were transfused 3.6 units of blood on average compared to 14.8 units in those with anteroposterior injury patterns [4]. In their retrospective study of 111 isolated pelvic fractures, Magnussen and colleagues found similar results. The 62 patients with lateral compression patterns averaged between 2.7 and 4.0 units of blood when transfused [5].

It is important to perform a detailed neurologic exam. Denis and colleagues in their retrospective review of 236 cases suggested a classification system. They classified Zone I fractures as those involving the region of the ala, Zone II as those involving the foramina, and Zone III as those involving the region of the central sacral canal. The authors noted a neurologic deficit in 5.9% of Zone I fractures, usually involving the L5 root. Zone II fractures had a neurologic injury attributable to the fracture in 28.4% of patients. These injuries are usually associated with sciatica and less commonly with bladder dysfunction. 56.7% of Zone III fractures had associated neurologic damage, most commonly involving bowel, bladder, and sexual function. The authors recommended using cystometrograms in all Zone III fractures [6]. Similar findings were noted by Gibbons and colleagues [7].

Attention should be given to the imaging modalities used to detect and assess pelvic fractures. Schicho and colleagues in 2016 emphasized the difficulty in assessment of posterior pelvic ring injuries on X-rays in patients over 75 years old. In 233 consecutive patients with blunt pelvic trauma aged 75 and older, they assessed the rate of injuries missed on plain X-ray and detected on CT. They found 51 sacral fractures on CT scan that were not detected on plain X-ray, yielding a sensitivity of 10.5%. They recommend based on this low sensitivity that consideration be given to pelvic CT scans in patients over 75 years old presenting with blunt pelvic trauma, particularly given the high mortality associated with missed fractures and prolonged immobilization and advances in treatment options [8].

Additionally, MRI can be a useful imaging adjunct to identify pelvic fractures not seen on plain X-ray. A retrospective review was conducted of 113 patients aged 60–102 years with hip pain and negative radiographs on whom MRI was performed. Of these patients, 38/113 (33.6%) had pelvic fractures found on MRI. Of the 38 patients with pelvic fractures, 23 had sacral fractures (60.5%) which is higher than previously reported in the literature. This study suggests that in a patient with a negative plain film but hip pain and high suspicion for hip fracture, MRI of both hips and the pelvis should be obtained [9].

Physical exam demonstrates that DP's neurologic function is intact.

Declaration of Specific Diagnosis

DP is a 43-year-old male who presents with a high-energy injury that consists of a right complete Zone I sacral fracture with ipsilateral superior and inferior pubic rami fractures without any evidence of neurologic or abdominal injuries.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Maintenance of pelvic ring integrity
2. Mobilization of the patient
3. Maintenance of muscle strength
4. Return to normal life activities

Treatment options include the following:

Conservative/nonoperative treatment:

1. Protected weight-bearing versus weight-bearing as tolerated

Surgical:

1. Iliosacral screw
2. Distraction external fixation
3. Neural decompression

Evaluation of the Literature

In order to identify relevant publications on sacral fractures, a PubMed search was performed. Keywords included the following: "sacrum" and "fracture." Articles in English from 1975 to 2011 were included in the search. This search identified 347 abstracts that were reviewed. From this search, 23 articles were read and reference lists were reviewed. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

As mentioned above, there are multiple treatment options for this patient with a complete Zone 1 sacral fracture with ipsilateral rami fractures. The following discussion explores the relevant literature in order to determine the most optimal treatment for DP.

Conservative/Nonoperative Treatment

In a retrospective review, Bruce and coworkers examined rates of displacement of 117 sacral fractures with initial displacement less than 5 mm. The lateral compression fractures were Denis Zone I or Zone II and were treated nonoperatively. Patients were allowed to weight-bear as tolerated unless other lower extremity injuries precluded weight-bearing. Zero out of five sacral fractures without associated rami fractures displaced. Zero of 54 incomplete fractures without a ramus fracture or with unilateral rami fractures displaced. Only 2 of 22 (9%) incomplete sacral fractures with bilateral rami fractures displaced. In contrast, 33% of complete sacral fractures with unilateral rami fractures displaced more than 5 mm. Additionally, 66% of complete sacral fractures with bilateral rami fractures displaced. Incomplete sacral fractures displaced at an overall rate of 2.6%, and complete fractures displaced at an overall rate of 50% [10]. The completeness of the sacral fracture and presence of associated rami fractures appear to be a good prognostic factor of future displacement greater than 5 mm. According to these results, DP has a 33% risk of displacing more than 5 mm with nonoperative treatment and weight-bearing, as he has a complete Zone I sacral fracture with ipsilateral rami fractures.

Sagi and coworkers retrospectively reviewed the role of stress examination under anesthesia in 68 patients with incomplete injuries to the posterior pelvic ring. This included patients with Young-Burgess APC-1, APC-2, LC-1, LC-2, and some LC-3 fracture patterns. Patients with incomplete and nondisplaced anterior compression fractures of the sacrum without internal rotation deformity were excluded. The exam under anesthesia demonstrated occult instability and affected the surgical decision-making in 50% of presumed APC-1 injuries, 39% of APC-2 injuries, and 35% of LC-1 injuries [11]. EUA may be a useful diagnostic tool and would be warranted for DP, as his sacral fracture is complete and his degree of instability is unknown.

Soles and coworkers conducted a retrospective review published in 2012 measuring displacement on follow-up radiographs of patients with minimally displaced lateral compression (LC) sacral fractures treated nonoperatively who followed an immediate weight-bearing as tolerated protocol. They included 118 patients with LC fractures with less than 10 mm of initial displacement. Of these, 117/118 (99%) healed without additional displacement seen on plain radiographs. Their results suggest that, for patients with minimally displaced LC fractures, immediate weight-bearing as tolerated reliably results in minimal additional displacement and union at the fracture site [12].

Surgical Treatment

Iliosacral Screw

Surgical treatment has been recommended for sacral fractures displaced more than 10 mm with satisfactory reduction of less than 5 mm [13]. Surgical treatment is aimed at deformity correction and pain relief. In a retrospective review of 38 patients with unstable pelvic ring injuries treated surgically, visual analog pain scores significantly decreased by 48% from 4.71 preoperatively to 2.85 postoperatively. Additionally, narcotic requirements decreased significantly by 25% from 2.26 mg of morphine per hour to 1.71 [14].

One surgical option is iliosacral screws. Iliosacral screws can either be placed after open reduction or percutaneously after closed reduction. Better reduction of the fracture site may be obtained with open means as compared to closed methods. Templeman and coworkers retrospectively reviewed 30 patients with sacral fractures displaced at least 1 cm, treated either with open reduction with iliosacral fixation or closed reduction and percutaneous fixation. The 17 patients treated with open reduction had an average preoperative displacement of 24 mm and a postoperative average of 4 mm. The 13 patients treated percutaneously had an average preoperative displacement of 15 mm and a postoperative average of 5 mm [13]. Matta and Tornetta demonstrated in a review of 107 operatively treated unstable pelvic fractures that an excellent or good reduction could be obtained in 95% of patients when open methods were utilized. Excellent reductions were less than 4 mm of displacement, and good reductions were 4–10 mm. Average posterior displacement for Tile B fractures was 10 mm preoperatively and 2 mm postoperatively. Average posterior displacement for Tile C fractures was 20 mm preoperatively and 4 mm postoperatively. The authors had more success when surgery was performed within 21 days of injury, achieving 75% excellent reductions when operated on within 21 days compared to 55% excellent reductions when operated on after 21 days [15]. However, open reduction may come with increased morbidity to the patient, such as bleeding, infection risk, and postoperative pain.

In a prospective study, Routt demonstrated that low rates of infection, blood loss, and nonunion can be expected with percutaneous iliosacral screw fixation. They stressed the importance of quality triplanar fluoroscopic imaging of an accurately reduced posterior pelvic ring. Of 177 consecutive patients treated, there were five misplaced screws due to surgeon error. One of these five resulted in a transient neuropraxia [16].

Gardner and coworkers demonstrated that iliosacral screws can be placed percutaneously using a standardized technique without electrodiagnostic monitoring with a low rate of neurologic complications. In their study population of 68 patients, they had a 0% incidence of neurologic injury. No planned percutaneous screws were abandoned because of inadequate fluoroscopic imaging. Postoperative CT scans demonstrated screw placement was intraosseous 70.8% of the time and juxtaforaminal in the other 29.2% [17].

It is of paramount importance that reduction of the sacroiliac joint be obtained before placement of iliosacral screws. In a cadaveric model of Zone II sacral fractures imaged with computed tomography, Reilly and coworkers demonstrated that cross-sectional contact area at the fracture site was decreased by 30%, 56%, 81%, and 90% at 5 mm, 10 mm, 15 mm, and 20 mm of cranial displacement, respectively. They also demonstrated that the volume of bone available for an iliosacral screw was decreased by 21%, 25%, 26%, and 34% for 5 mm, 10 mm, 15 mm, and 20 mm of displacement, respectively. Two iliosacral screws could not be contained in 50% of specimens with 15 mm of displacement and in 66% of specimens with 20 mm of displacement [18].

Two screws, either both in S1 or one in S1 and one in S2, have been shown to be biomechanically superior to one S1 screw in rotational stiffness and load to failure in a completely unstable pelvis model without anterior pelvic fixation [19].

In a biomechanical evaluation of pullout strength of 7.0-mm cannulated screws in a cadaveric model, long-threaded screws placed in the sacral body had a pullout strength of 925 N and were shown to be superior to short-threaded screws in the body or in the ala [20]. However, fully threaded screws should be considered in treating sacral fractures, as compression of the cancellous sacral fracture may damage the foraminal nerve roots. A fully threaded screw should be considered for DP to avoid over compression, in turn minimizing an internal rotation deformity.

Distraction External Fixation

In a prospective study of 14 consecutive patients with vertically stable lateral compression pelvic fractures, Bellabarba and coworkers demonstrated the efficacy of distraction external fixation in treating these injuries. Preoperative internal rotation deformity averaged 25°, and posterior injuries consisted of sacral compression fractures in all patients. The fixator consisted of a two-pin, single-bar, supraacetabular construct. The internal rotation deformities were reduced with closed methods using the supraacetabular Schanz screws. A symmetric reduction was obtained of both hemipelves in all patients. Patients were allowed to fully weight-bear postoperatively. Average time to weight-bearing without assist device was 12 days. Complications included three pin tract infections treated successfully with oral antibiotics, one transient lateral femoral cutaneous nerve palsy, and one late pin tract abscess after removal requiring debridement and antibiotics [21]. Distraction external fixation would be unnecessary for DP, as he has no significant internal rotation deformity seen on his imaging.

Neural Decompression

Of the seven patients Denis and coworkers treated with a foot drop, five were treated conservatively. Three of these five did not recover, one improved, and one completely recovered. Of the two treated surgically, one recovered, and the other recovered followed by a recurrence of foot drop after loss of reduction secondary to early ambulation. He suggested that early decompression with anatomic reduction may improve results [6].

In a review of 13 patients with displaced sacral fractures and neurological deficit, those who underwent early decompression had a significantly better neurological improvement and better physical function as measured by the modified SOFCOT Index and the SF-36, respectively, at an average follow-up of 27.1 months compared to those who did not have decompression [22].

Decompression performed later after fracture healing proves to be more difficult secondary to epineural fibrosis and scarring of the foramina and central canal, and results are disappointing [6]. DP would not benefit from neural decompression, as he has no neurologic deficits.

Low-Energy Traumatic Fractures of the Pelvis

In the literature reviewed since 2011, the subject of pelvic and sacral fractures from low-energy trauma was addressed in several articles. Sullivan and coworkers reported the epidemiology of pelvic fractures in the geriatric population based on the Nationwide Inpatient Sample (NIS). In the 18-year period reviewed in the study, the incidence of pelvic fractures increased by 24%. This is as compared with intertrochanteric and femoral neck fractures with a peak in 1996 and a decrease in incidence by 25.7% by the year 2010 [23].

Mears and Berry in 2011 conducted a retrospective review of 181 patients with displaced and nondisplaced pelvic fractures in patients 65 years and older. In all patients, they reported a 1-year mortality of 23% and 47% at 3 years. They reported differences in acute treatment and increased duration of hospitalization among patients with displaced pelvic fractures and compared with those with nondisplaced fractures. Most notably, no difference was detected between in-hospital complications or 30-day, 90-day, or 1-year mortality rates between displaced and nondisplaced pelvic fractures [24].

In 2013, Rommens and Hofmann proposed a classification for fragility fractures of the pelvis based on analysis of 245 patients presenting with this type of fractures. Elderly patients commonly have weaker bone in which the ligaments are stronger than the bony structures. The movement and displacement of the fracture fragments are limited by the ligamentous anatomy, and assessment of stability is not necessarily the same as in young patients with high-energy mechanisms. The classification of fragility fractures of the pelvis (FFP) falls into four types that progress from most stable to least stable. FFP Type I is an anterior injury only; Type II is a nondisplaced posterior injury; Type III is a displaced unilateral posterior injury; and Type IV is a displaced bilateral posterior injury. Within each type, there are several subtypes. This classification is meant to assist in selection of appropriate surgical candidates [25].

The appropriate indications for surgical treatment of fragility fractures of the pelvis were reviewed in articles by Wagner and associates and Rommens and colleagues. Both articles recommend treatment algorithms based on the above classification system with Type I and II lesions treated nonoperatively and Type III and IV treated with ORIF. Both papers were review articles and did not report patient outcomes [26, 27].

Literature Inconsistencies

The major challenge throughout the literature addressing treatment of sacral fractures is clearly the lack of randomized prospective controlled trials. The majority of the evidence is driven by retrospective cohort studies or at best prospective cohorts. More prospective randomized data are needed to better guide decision-making.

Evidentiary Table and Selection of Treatment Method

The key studies in treating DP are noted in Table 13.1 [10–12, 17, 22]. Based on the literature, the authors feel that the best treatment in this case would be examination under anesthesia for occult instability. If the fracture was stable with stress examination, treatment would consist of weight-bearing as tolerated and serial radiographs. If the fracture was unstable with stress examination, treatment would consist of a percutaneous fully threaded iliosacral screws with protected weight-bearing.

Definitive Treatment Plan

DP should be treated with stress examination under anesthesia for his complete sacral fracture with ipsilateral rami fractures, without associated neurologic deficits. According to the results presented by Bruce and colleagues, DP's fracture pattern would be expected to displace more than 5 mm in 33% of patients. Sagi and colleagues also found occult instability on examination under anesthesia in 35% of patients with LC-1 fracture patterns. If the stress examination did not demonstrate any occult instability, the patient would be allowed to weight-bear on his right lower extremity. After mobilization with physical therapy, pain would be reassessed, and repeat radiographs including inlet and outlet views would be obtained to assess for any displacement. If there was not any displacement and pain was controlled, DP would be discharged home with follow-up in 2 weeks. New radiographs and follow-up would be performed at 2, 6, and 10 weeks after injury.

If DP's stress examination did demonstrate instability, one or two percutaneous iliosacral

Table 13.1 Evidentiary table: A summary of the quality of evidence for conservative treatment of incomplete sacral fractures

Author (year)	Description	Summary of results	Level of evidence
Bruce et al. (2011) [10]	Retrospective case series	117 patients with less than 5 mm of initial displacement treated nonoperatively. Incomplete sacral fractures with ipsilateral rami fractures had no displaced unions. Complete sacral fractures with bilateral rami fractures displaced at 68%	IV
Sagi et al. (2011) [11]	Retrospective chart and radiographic review	68 patients with incomplete posterior pelvic ring injury undergoing examination under anesthesia. Surgical treatment changed in 50% APC-1, 39% APC-2, and 35% LC-1	IV
Gardner et al. (2009) [17]	Prospective case-control	68 patients treated with 106 iliosacral screws without neurodiagnostic monitoring. No neurologic injuries and no abandoned screw placement. Screws intraosseous 70.8% and juxtaforaminal 29.2%	III
Zelle et al. (2004) [22]	Retrospective comparative study	13 patients with sacral fracture and neurologic deficit with average follow-up of 27.1 months. Patients undergoing decompression had better neurologic improvement on SOFCOT index and better physical function on SF-36	III
Soles et al. (2012) [12]	Retrospective review	Nonoperative treatment consisted of immediate foot-flat mobilization and advancement of weight-bearing as tolerated. One patient failed nonoperative management, demonstrating 5 mm of additional sacral displacement and having substantial pain with attempts to mobilize. The other 117 patients (99%) healed with minimal additional displacement	IV

screws would be placed, depending on the ability to safely place a second screw either in S1 or S2. The patient would be placed supine with a bump underneath the middle of his pelvis. A guide wire would be placed percutaneously in the appropriate position up to the lateral border of the S1 foramen using perfect inlet and outlet fluoroscopic views. A perfect lateral image would then be obtained to make sure that the wire is posterior to the iliocortical density and anterior to the sacral foramen. If the wire is in a safe and appropriate location, it would be advanced into the sacral body. The length would then be measured, and a fully threaded 7.0-mm or 7.3-mm screw with a washer would be placed over the wire. Postoperatively the patient would use protected weight-bearing and be followed with serial radiographs at 2, 6, and 10 weeks after injury to monitor for displacement. At 10 weeks the patient would be advanced to weight-bearing as tolerated.

Predicting Long-Term Outcomes

In the long term, patients with incomplete sacral fractures without neurologic deficits do quite well. In a review of 218 patients with an average follow-up of 5.6 years, Tile found that of the 184 vertically stable pelvic fractures, most had few major long-term problems, and if any pain was present, it was usually mild or moderate. In contrast, 60% of the 34 with vertically unstable fractures continued to have pain [28].

Tornetta reported on outcomes of operatively treated unstable posterior pelvic ring injuries. At an average follow-up of 44 months, 66% of the 46 patients returned to their original jobs. Sixty-three percent had no pain or pain only with strenuous activity and ambulated without limitation. Despite these results, 35% of patients had a neurologic injury that compromised their final result [29].

Templeman and colleagues also demonstrated that the presence of a neurologic injury is the most important factor of outcome in patients with a displaced sacral fracture. In a retrospective review of 27 patients with displaced sacral fractures who were all treated with internal fixation, those patients without neurologic injury had significantly higher Iowa pelvic scores compared to those with neurologic injury. 13 of 15 patients without nerve injuries were able to return to work full time [13].

DP has a complete fracture and does not have any neurologic injury or significant displacement, and as such should be expected to do very well with stress examination under anesthesia and possible percutaneous iliosacral screw fixation.

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Pelvic Ring Injury II

14

Matthew D. Karam, Adam Keith Lee, and David C. Templeman

DP: 33-Year-Old Man with Pelvic Ring Injury

Case Presentation

DP is a 33-year-old man who complains of severe left pelvic pain after falling out of a window. He is transferred to the emergency department via EMS. On presentation, he demonstrates a GCS of 15 and denies any loss of consciousness. On primary survey, his airway is patent, and he is hemodynamically stable. On secondary survey, he demonstrates severe pain with manipulation of his pelvis on the left side. His secondary survey is otherwise negative.

His past medical history is negative. He takes no medications and has no allergies.

M. D. Karam
Department of Orthopedics and Rehabilitation, University of Iowa Hospitals and Clinics, Department of Orthopedics and Rehabilitation, University of Iowa, Iowa City, IA, USA

A. K. Lee (✉)
Department of Orthopedic Surgery, Keck School of Medicine of University of Southern California, Los Angeles, CA, USA
e-mail: Lee74@marshall.edu

D. C. Templeman
University of Minnesota, Hennepin County Medical Center, Minneapolis, MN, USA

On physical examination, his pelvis is unstable to stress examination. He is neurologically intact.

Radiographs and CT of the pelvis are demonstrated in Figs. 14.1a–c and 14.2a, b.

Interpretation of Clinical Presentation

DP's symptoms and findings are consistent with an injury to the left hemipelvis. This patient has a symphysis pubis diastasis, classified as a Burgess APC-II pelvic ring disruption. The majority of pelvic ring injuries, including isolated rami fractures, are low energy and stable [1]. However, these injuries in young healthy patients often result from high-energy mechanisms such as motor vehicle collisions or falls from height as in the present patient. Given this association, routine clearance of the head, chest, and abdomen by emergency department or surgical trauma personnel is warranted. In a large retrospective analysis, Giannoudis and colleagues determined that pelvic ring injuries were most commonly associated with chest trauma with > AIS 2 severity in 21.2% of the patients, head injuries (>AIS 2) in 16.9%, liver or spleen injuries in 8.0%, and two or more long bone fractures in 7.8% [2].

Knowledge of the mechanism of injury obtained from either the patient or emergency personnel can provide vital clues as to the direction and magnitude of the force that resulted in the injury. The

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Fig. 14.1 (**a**–**c**) Radiographs of the pelvis are demonstrated. (**a**) AP pelvis. (**b**) Inlet view. (**c**) Outlet view

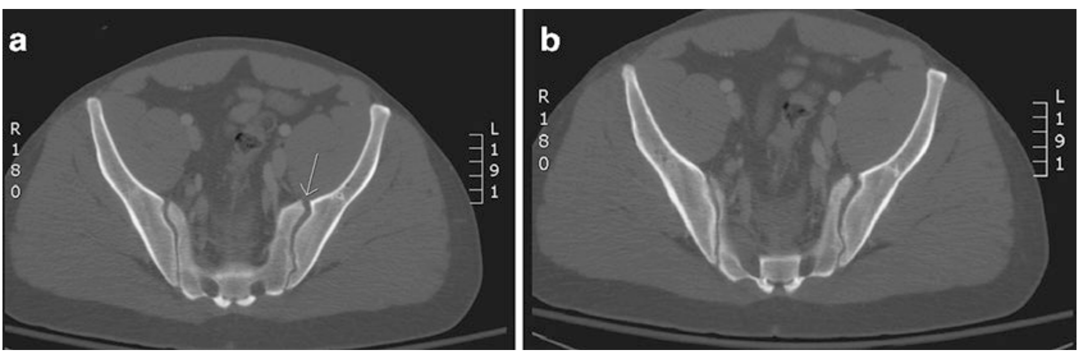

Fig. 14.2 (**a**, **b**) Axial CT images of the pelvis are demonstrated

mechanism and resulting injury pattern as well as initial vital signs and laboratory values have been shown to correlate with fluid resuscitation requirements, blood loss, intrapelvic hemorrhage, and associated injury patterns, thus creating an initial risk profile that can guide early treatment in patients with unstable pelvic fractures [3–5].

Initial examination of the patient with a pelvic ring injury is of critical importance. Signs of external trauma such as flank ecchymosis or bruising may indicate underlying hemorrhage or the presence of a Morel-Lavalle (degloving) lesion [6, 7]. Detailed systematic inspection for open fracture or urogenital trauma should be performed, including vaginal and rectal exams. Urologic injuries are common in patients with anterior pelvic trauma [8]. In male patients, a retrograde urethrogram should be obtained to ensure that the urethra is intact before passing a Foley catheter [9]. Extravasation of dye during the urethrogram is a contraindication to blind passage of a Foley catheter and requires consultation with a urologist. The presence of blood at the tip of the penile meatus can be a sign of urethral trauma; however, it is not present in the majority of patients [10]. When the urethra is intact, a Foley catheter is passed, and a cystogram is obtained. Because the female urethra is short and less prone to injury, a retrograde urethrogram is not required before inserting a Foley catheter. The bladder should be studied by cystography with an intravenous pyelogram or retrograde cystogram particularly if >25 RBC/HPF are identified on urinalysis [9, 10]. External compression of the bladder may be caused by a pelvic hematoma, and the magnitude of compression and shape of the cystogram can be an indirect clue as to the extent of intrapelvic hemorrhage.

Motion if noted on manual examination of the pelvis is a sign of instability; this maneuver should not be repeated. In awake patients, palpation of the posterior pelvis is thought to be helpful in determining the presence of an injury to the posterior ring [11]. In patients who demonstrate hemodynamic instability with external rotation patterns, a sheet or binder should be placed at the trochanters to reduce pelvic volume and hence potential space for hemorrhage [12–14]. Recent biomechanical cadaver studies demonstrated that external compression devices can lead to advantageous realignment and reduction of pelvic fractures without overreduction or fracture displacement (defined >5 mm) [15–17]. Heini and colleagues reported on the application of a pelvic resuscitation clamp to be “hemodynamically effective” in 10/30 patients [18]. Pelvic wrapping or a binder is now recommended as part of the resuscitation of unstable pelvic ring injuries by the US Army Institute Of Surgical Research [19]. In the present patient, without evidence of hemodynamic instability, pelvic wrapping or binder placement is not indicated.

An AP pelvis radiograph should be obtained on all trauma patients on arrival to the emergency center. Inlet and outlet views are helpful in further characterization of the pelvic ring injury. CT imaging, including reformations, although not essential in initial management, can provide further insight into the injury, particularly in the region of the sacroiliac joint. CT has been demonstrated to improve the accuracy of diagnosis and classification [20].

Various classification systems are commonly used when describing pelvic ring injuries. The Young-Burgess system describes the force and magnitude by subdividing injury patterns based on lateral (LC) versus anterior compression (APC) vectors. Vertical shear (VS) injuries are characterized by vertical migration of the hemipelvis from disruption of ligamentous restraints. Bucholz and colleagues described pelvic ring stability based on propensity to resist further rotation or vertical translation [21].

It has been shown that the Young-Burgess system is useful for predicting transfusion requirements in patients like DP. For the system to predict mortality or non-orthopedic injuries, fractures were divided into stable (APC1, LC1) or unstable (APC2, APC3, LC2, LC3, VS, combined mechanism of injury) types [22, 23] (Figs. 14.1a–c and 14.2a, b).

Review of the images in the present case demonstrates several findings. The AP pelvis most notably reveals pubic symphysis diastasis. By measuring the difference in the femoral head height from a line perpendicular to the axis of the sacrum, leg length discrepancy can be assessed [24]. Keeping this in mind, in the present case apparent leg length discrepancy is likely accounted for by the obliquity of the image. The pelvic inlet view again demonstrates symphysis diastasis. In addition, this view also allows further evaluation of rotation and anterior/posterior displacement of the pelvis. As one can see, there is slight external rotation of the left hemipelvis. The outlet view is helpful in identifying sacral fractures as well as vertical displacement in the plane of the pelvis [25].

Review of the outlet view in the present patient reveals symmetric heights of the iliac crests and ischial tuberosities indicating vertical stability. There are no sacral fractures identified. The axial computed tomographic image demonstrates widening of the anterior aspect of the sacroiliac joint with slight external rotation of the left hemipelvis.

Declaration of Specific Diagnosis

Based on initial evaluation and review of the images, it appears that our patient DP has sustained an APC-II pelvic ring injury with symphysis diastasis, with further injury to the anterior SI ligamentous complex leading to external rotation of the left hemipelvis.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Anatomic restoration of bony alignment
2. Restoration of pelvic stability
3. Mobilization of the patient

Treatment options include:

1. Nonsurgical management
2. Symphyseal plating
3. External fixation
4. Posterior fixation/SI screws in addition to symphyseal plating

Evaluation of the Literature

In order to identify relevant publications on treatment of APC II pelvic ring injuries, a PubMed search was performed. The search was limited from 1975 to 2011. A search with the following operators was performed: "rotationally" and "unstable" and "pelvic ring injury" (27 titles) or "fracture" (37 titles). From this search all abstracts were reviewed for applicability. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

Conservative/Nonoperative Treatment

Until the early 1980s, nonsurgical management was common for the majority of pelvic fractures. Fell and colleagues [26] reviewed 114 patients (average 7 years) who underwent nonoperative management of pelvic ring injuries (68 type A, 20 type B, 26 type C). Outcomes were noted to be worse in patients with increasing degrees of pelvic instability. The most notable long-term complication was pain in the lumbo- or iliosacral region. Contraindications to internal fixation of the symphysis pubis include unstable, critically ill patients; severe open fractures with inadequate wound debridement; and crushing injuries in which compromised skin may not tolerate a surgical incision. Suprapubic catheters placed to treat extraperitoneal bladder ruptures may result in contamination of the retropubic space and are a relative contraindication to internal fixation of the adjacent symphysis pubis. Of particular interest is that in obese patients (BMI >30 kg/m^2) who undergo pelvic fixation (including anterior only fixation), there is a 54% risk of subsequent complications, including wound infection and dehiscence, loss of reduction, iatrogenic nerve injury, deep venous thrombosis, pneumonia, and the development of decubitus ulcers [27]. Additional conditions that may preclude secure fixation are osteoporosis and severe fracture comminution of the anterior pelvic ring.

Surgical Management

The primary treatment goal in surgical fixation of pelvic ring injury is anatomic restoration of bony alignment and stability [28]. As defined by Olson and colleagues, a stable pelvic ring injury can be defined as one that will withstand the physiologic forces incurred with protected weight bearing (and/or bed to chair mobilization without abnormal deformation of the pelvis) until bony union or soft tissue healing can occur [1]. The indication therefore for reduction and fixation of pelvic ring injuries is the presence of predictable instability and/or deformity of the pelvic ring.

Pelvic ring injuries have historically been associated with increased rates of sitting imbalance, gait alteration, back pain, and genitourinary dysfunction [29]. Worse results have been correlated with initial displacement, displacement at union, anatomic location of the injury, and residual neurologic dysfunction [29]. In order to achieve the goal of pelvic stability, we must determine which injury patterns have a propensity for instability and thus require fixation.

In AP injuries symphysis diastasis is generally limited to 2.5 cm or less if the remainder of ligamentous structures remain intact [30]. As in the present patient, diastasis of the pubic symphysis >2.5 cm coupled with external rotation of the innominate bone indicates injury to the anterior SI ligamentous complex and inherent rotational instability [31, 32].

Symphyseal Plating

An initial symphysis pubis diastasis of greater than or equal to 2.5 cm is an indication for open reduction and internal fixation [33–35]. Internal fixation is performed to relieve pain and improve stability of the anterior pelvic ring. The indications for surgery are based on the patient's overall condition and the stability of the entire pelvic ring.

Biomechanical studies have demonstrated that internal fixation is superior to external fixation in resisting vertical displacement of the hemipelvis [36]. Several different implants may be used for fixation of the disrupted symphysis. Advocates of two-hole plate techniques claim that the plate can act as a universal joint, and slight implant loosening permits the return of physiologic motion of the symphysis after fixation. This theoretically reduces the late problems of implant failures. However, a large retrospective review comparing two-hole and multi-hole plates (minimum two screws on each side of the symphysis) found that two-hole fixation was associated with a statistically significant ($p < 0.05$) increase in fixation failures and malunions [37].

The most frequently used implants are pelvic reconstruction plates with either four or six holes. Pre-curved plates (which are 3.6 mm thick and unlike straight plates of 2.8 mm thickness) provide additional stability. The use of locking plates has been met with both success and failure. There are no comparative studies, but observations of several failures point to the benefits of allowing motion between the plate and the screw heads as symphyseal motion returns with weight-bearing.

The retrospective study by Tornetta and colleagues [33] is most germane to the present patient. Twenty-nine patients with unstable rotational pelvic ring injuries were treated operatively and observed for an average of 39 months. Follow-up evaluation demonstrated a high functional success rate, with 96% of patients having no pain or pain only with strenuous activity. The majority of patients in this study ambulated without assistance or limitations and returned to work.

External Fixation

External fixation clearly has a role in the acute management of pelvic ring injury [38]. The role in definitive management is less clear. Pin site infection is a common complication noted with the use of pelvic external fixation. Mason and colleagues noted a 62% complication rate and nearly 50% rate of pin site infection in patients undergoing definitive management of a pelvic ring injury with external fixation [39]. Hip impingement secondary to an exostosis caused by a supra-acetabular pin has also been reported [40].

Recent studies highlight the importance of careful application of an anterior pelvic external fixator, as it can lead to increased deformity in the setting of a type III instability and make definitive management more difficult [41, 42].

A significantly higher incidence of inability to obtain or maintain reduction of open-book pelvic fractures in obese patients using primary anterior uniplanar external fixation has also been demonstrated [43]. In the present patient, if it was determined that an injury requiring suprapubic catheterization was necessary, an anterior external fixator may be considered for temporary management.

Anterior internal fixation (INFIX) is a technique in which large-diameter (7–8 mm) pedicle screws are inserted into the supra-acetabular region and coupled to a bar, which is tunneled subcutaneously that may allow for fewer pin site complications and increased mobility [44–47]. Vaidya and coworkers reported on two series of patients treated with this technique and saw minimal complications, most commonly heterotopic ossification and lateral femoral cutaneous nerve irritation. They recommend INFIX as an alternative to external fixation in obese individuals meeting the above indications for external fixation [48, 49]. However, postoperative femoral nerve palsy has also been reported, and caution should be exercised when selecting patients for this novel intervention [50]. This technique has limited indications though early reports are promising; further study will help to define its role in patients like DP.

Posterior Iliosacral Screw Fixation

Evidence exists, that particularly in vertically unstable pelvic ring injuries, a role exists for posterior iliosacral screw fixation [51–53]. This role, in patients like DP who sustain APC II injuries (rotationally unstable) with inherent vertical stability, has not been demonstrated. To investigate whether the combination of sacroiliac screw fixation with anterior plate fixation provides additional stability compared with isolated anterior plate fixation in Tile B fractures, Van den Bosch and associates loaded six embalmed pelves and measured the displacements of the fracture parts using a three-dimensional video system [54]. They demonstrated that the addition of a single sacroiliac screw did not provide additional stability (translation and rotation stiffness) as compared to an isolated anterior plate when loaded up to 300 Newtons. There is a relative paucity of clinical evidence supporting the use of posterior iliosacral screw fixation in isolation or as an adjunct to symphyseal plating in APC II pelvic ring injuries. Tornetta and associates [33] achieved a 96% success rate in rotationally unstable pelvic ring injuries with anterior plate fixation alone. Although the use of iliosacral screw fixation introduces the potential risk of iatrogenic nerve injury, the exact risk and clinical implications are difficult to elucidate [55, 56]. Therefore, the routine use of posterior iliosacral screw fixation cannot be recommended for this specific injury pattern.

Literature Inconsistencies

There are several challenges in evaluating literature regarding this injury pattern. There is the lack of universally accepted terminology and multiplicity of accepted injury classification schemes. Further, the majority of currently available data on fixation of rotationally unstable pelvic injuries is level III/IV (case–control, retrospective comparative, systematic reviews) and makes definitive, evidence-based practice difficult. While few studies have case–control comparison methodology, no study has a control group comparing different treatments. More prospective data are needed to further delineate and guide decision making.

Evidentiary Table and Selection of Treatment Method

The key studies in treating DP are noted in Table 14.1 [33, 49, 57–62]. Based on the literature available, the authors feel that the best treatment in this case would be open reduction and internal fixation of the symphysis pubis with use of a pelvic reconstruction plate.

Definitive Treatment Plan

Based on the presently available literature, and after a thorough evaluation of the patient's history, physical examination, and imaging, this patient would best be treated with anterior open reduction and internal fixation with a multi-hole pelvic reconstruction plate.

Table 14.1 Evidentiary table: A summary of the quality of evidence for rotationally unstable pelvic ring injuries

Author (year)	Description	Summary of results	Level of evidence
Borg et al. (2010) [57]	Prospective, observational	45 patients with surgically managed pelvic ring injuries (B and C), followed for 2 years, reported SF36 PCS significantly lower than reference population	IV
Van den Bosch et al. (1999) [58]	Retrospective	37 patients with surgically managed pelvic ring injuries (B and C), followed for an average of 36 months, reported SF36 PCS of 67.2 (normal 81.9). 60% of patients reported alterations in sitting. 40% reported change in sexual intercourse	IV
Gruen et al. (1995) [59]	Retrospective	48 patients with surgically managed pelvic ring injuries (B and C), followed for a minimum of 1 year, 37 (77%) of the patients had mild disability (total SIP <10). 11 (23%) of the patients had moderate disability (SIP >10) at 1 year. Of the patients who were employed preinjury, 76% were employed 1 year post injury; 62% had returned to full-time work, and 14% had returned with job modification	IV
Putnis et al. (2011) [60]	Retrospective	49 patients with surgically managed pelvic ring injuries (B and C), including anterior fixation, followed for a minimum of 1 year, demonstrated physical health (SF-12 scoring), that was lower than the normal population (42.5 vs. 50)	IV
Oliver et al. (1996) [61]	Prospective cohort	35 patients with surgically managed pelvic ring injuries (B and C), followed for an average of 2 years, reported a 14% impairment in physical outcome score (SF36) as compared to normal population	III
Pohleman et al. (1996) [62]	Prospective cohort	58 patients with surgically managed pelvic ring injuries (B and C), followed for an average of 28 months, reported 79% good to excellent results in type B patterns and 27% good to excellent results in type C patterns	III
Tornetta et al. (1996) [33]	Retrospective	29 patients with surgically managed rotationally unstable pelvic ring injuries, followed for an average of 39 months, reported full ambulation (96%), no pain (69%), pain with strenuous activity (27%), normal muscle strength (96%), and back to work (83%)	IV
Vaidya et al. (2012) [49]	Retrospective review	Retrospectively reviewed 91 patients who incurred an unstable pelvic injury treated with an anterior internal fixator and posterior fixation. All 91 patients were able to sit, stand, and lie on their sides. Injuries healed without loss of reduction in 89 of 91 patients. Complications included six early revisions resulting from technical error and three infections. Irritation of the lateral femoral cutaneous nerve was reported in 27 of 91 patients and resolved in all but one. Heterotopic ossification around the implants, which was asymptomatic in all cases, occurred in 32 of 91 patients	IV

Predicting Outcomes

When considering at all anterior pelvic ring injury patterns, numerous complications have been reported. Collinge and associates [63] described 20 patients who sustained saddle horn injuries and were assessed at an average of 33 months after the injury. They noted that 17 patients had returned to riding horses, and ten felt that they had returned to their previous level of recreation, which had been "heavy" in nine cases and "moderate" in one. Eighteen patients had returned to their previous employment. Eighteen patients were found to have sexual dysfunction at the time of the latest follow-up. The mean Iowa pelvic score was 84 points (range, 56–99 points). The Short Form-36 outcomes scores were diminished in two subsections, role physical and role emotional, compared with population norms. In females, a higher risk of dyspareunia, urinary difficulty, and pregnancy-related issues with an increase in the need for C-section has been reported [64]. In elderly patients (defined age > 55) who sustained a pelvic fracture, there was a significantly higher mortality rate when compared to younger patients, which should be used to guide initial management [65].

According to the best currently available literature regarding this specific injury, and without perioperative complication, the patient can expect only slight impairment in his overall physical function in the short term. Further, he may anticipate a full return of muscle strength and ambulation ability in approximately 3 years [33].

Further studies are needed to predict longer-term functional outcomes.

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15 Femoral Neck Fractures in the Elderly

David Polga and Robert T. Trousdale

WO: A 65-Year-Old Female with Hip Pain

Case Presentation

WO is a 65-year-old female who presents to the emergency department with a chief complaint of left hip pain after falling on an icy surface. She is an independent community ambulator and denies any other injuries or pain. On presentation, she demonstrates a GCS of 15 and denies any loss of consciousness. On primary survey, her airway is patent, and she is hemodynamically stable. On secondary survey, she demonstrates severe pain with manipulation of the left hip. Her secondary survey is otherwise negative.

She is a healthy female with no past medical history. She takes no medications and has no allergies.

On physical exam, the patient is a healthy-appearing female in no acute distress. She is hemodynamically stable, awake, and alert. The patient has tremendous pain, with passive range of motion of the left hip. The dorsalis pedis and posterior tibialis pulses are palpable; sensation to light touch is intact in all distributions.

Radiographs of the pelvis and left hip are demonstrated in Figs. 15.1 and 15.2a, b.

Interpretation of Clinical Presentation

This 65-year-old female presents with a displaced femoral neck fracture after a ground level fall. No other injuries are reported. She is an independent community ambulator and has no past medical history. Her X-rays reveal a displaced femoral neck fracture. Initial emergency room management includes a screening for other injuries and evaluation for other active medical problems. After admission to the hospital, consultation with an internal medicine specialist is appropriate in the preoperative workup of this patient.

This is a common clinical scenario with 329,000 hip fractures in the United States reported in 2004 [1]. With an increasing percentage of the population over the age of 65, a concomitant increase in the number of femoral neck fractures is anticipated.

D. Polga (✉)
Department of Orthopedic Surgery, Marshfield Clinic, Marshfield, WI, USA
e-mail: Polga.david@marshfieldclinic.org

R. T. Trousdale
Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, USA

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Declaration of Specific Diagnosis

WO is a healthy 65-year-old female with a displaced left femoral neck fracture after a fall from standing height.

Brainstorming: What Are the Treatment Goals and Options?

Treatment Goals:

Treatment goals are to relieve injury related pain, to allow early mobilization, and to return patient to preinjury level of function while minimizing perioperative surgical and medical complications.

Fig. 15.1 AP radiograph of the pelvis

Treatment Options:

1. Nonoperative management
2. Internal fixation
3. Arthroplasty
   (a) Total hip arthroplasty versus hemiarthroplasty
   (b) Unipolar versus bipolar hemiarthroplasty
   (c) Cemented versus uncemented stem fixation

Evaluation of the Literature

A detailed literature review was carried out to identify articles published from 1975 that present relevant to this topic. PubMed was searched with a combination of terms including "femoral neck fracture", "arthroplasty", and "internal fixation". This search revealed 5195 articles. References of identified articles were further reviewed to capture additional literature. Attempts were made to limit inclusion to the highest level of evidence for each area (i.e., randomized trials). For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

Nonoperative Management

It is common practice to treat displaced femoral neck fractures with surgical intervention. It seems

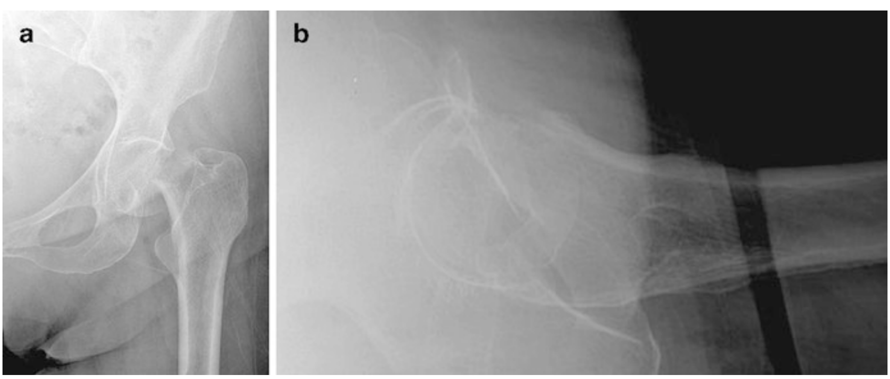

Fig. 15.2 (**a**) AP radiograph of the hip. (**b**) Lateral radiograph of the hip

logical to address pain control through stabilization of the fracture or through arthroplasty in order to attempt mobilization of these patients when their condition permits to prevent complication associated with prolonged bed rest such as pressure sores, pneumonia, thromboembolic disease, and urinary tract infections. Nonoperative care may be appropriate when pain control is adequate, and the risks associated when medical comorbidities outweigh the benefits of surgery. There are studies addressing nonoperative treatment for nondisplaced, valgus-impacted femoral neck fractures [2], and in this fracture type, the advantages of internal fixation are a decreased risk of late fracture displacement and need for further surgery [3]. There are a limited number of studies addressing displaced hip fractures. A retrospective review of intracapsular and extracapsular hip fractures treated nonoperatively without further details of fracture type had a significantly lower 30-day mortality rate with operative treatment when compared to nonoperative treatment. In nonoperative patients treated with early mobilization, there was a lower in-hospital and 30-day mortality rate compared to those treated with bed rest [4]. Gregory and coworkers retrospectively reviewed 102 displaced femoral neck fractures treated with either Austin Moore hemiarthroplasty or nonoperative treatment of early mobilization. Nonoperative treatment was indicated in patients with high perioperative risks as judged by the provider. There was a greater mortality rate at 30 days and 1 year in the nonoperative group. However, of those patients in the nonoperative group that survived past 30 days, their mortality rate was similar to those who had surgery [5]. Typically, elderly patients with a displaced femoral neck fracture should be treated operatively unless medical contraindications to surgical care exist.

Operative Management

Internal Fixation

Options for operative intervention for the treatment of displaced femoral neck fractures include fracture reduction with internal fixation and arthroplasty. Several randomized controlled studies have compared these treatment options in elderly patients. Results from these trials have also been compiled and analyzed in meta-analyses.

The results of a multicenter trial of 450 patients over the age of 70 with displaced femoral neck fractures, randomized to treatment with internal fixation or arthroplasty, were reported at 2 and 10 years [6, 7]. Failure of internal fixation was defined as nonunion, failure of fixation, osteonecrosis, or infection, while failure of arthroplasty was defined as two or more dislocations, periprosthetic fracture, aseptic loosening, or infection. At 10-year follow-up, there was a 45.6% failure rate after internal fixation compared to an 8.8% arthroplasty failure rate. Moreover, most of these failures occurred by the 2-year follow-up (43% internal fixation; 6% arthroplasty). There was no difference in mortality between the groups at any time point. However, 36% of patients in the internal fixation group reported impaired walking ability, and 6% reported severe pain at 2 years. This was significantly higher than the 25% impaired walking and 1.5% severe pain reported in the arthroplasty group.

Keating and coworkers randomized patients with displaced femoral neck fractures to fixation versus hemiarthroplasty or total hip arthroplasty [8]. Thirty-nine percent of patients treated with internal fixation required a secondary operation which was significantly more than those treated with arthroplasty. The hip function scores in the fixation group were also lower. While the initial cost of internal fixation was less compared to arthroplasty, there was an increased late cost due to the high rate of revision surgery.

Bhandari and coworkers performed a meta-analysis of nine randomized controlled trials that included 1162 patients treated with internal fixation versus arthroplasty [9]. Treatment with arthroplasty resulted in a relative risk reduction of revision surgery of 77% compared to treatment with internal fixation. However, arthroplasty was associated with increased infection rates, blood loss, and operative time. Both treatment methods were similar with regard to pain relief and hip function. Their data also suggested the possibility that arthroplasty may be associated with a slight increase in early mortality rate.

Another meta-analysis of 14 randomized controlled trials including 2289 patients reported similar findings with reduced risk of revision surgery when treated with arthroplasty compared with internal fixation [10]. However, these data did not find a mortality difference at 30 days and 1 year when the two treatment methods were compared. Additionally, the authors reported that most trials included in their review found less pain and better function in patients treated with arthroplasty. Similar findings were reported by Gao and colleagues who published a meta-analysis that included 20 randomized controlled trials involving 4508 patients. The arthroplasty group had fewer major complications, lower incidence of reoperation, and better pain and function compared to the internal fixation group. Despite this, mortality rates at 1 and 3 years after surgery were similar [11]. In multiple studies and meta-analyses, arthroplasty consistently provides improved outcomes in an elderly population but may not decrease mortality rate compared with internal fixation.

Arthroplasty

Total Hip Arthroplasty Versus Hemiarthroplasty

Hemiarthroplasty and total hip arthroplasty (THA) have both been used to treat displaced femoral neck fractures in elderly patients. Total hip replacement is a logical choice in those patients with antecedent hip pain from preexisting hip disease. The decision on which of these options is better in other patients is a controversial topic and has been evaluated in a prospective, randomized manner. While several studies have compared internal fixation, THA, and hemiarthroplasty, others focus only on patients treated with either hemiarthroplasty or total hip replacement. Studies that compare modern implants and techniques will be reviewed.

In a multicenter, prospective, randomized trial, Baker and colleagues treated 81 patients with either a unipolar hemiarthroplasty or THA [12]. Inclusion criteria included age over 60 years, normal cognitive testing, ability to walk at least 0.5 miles, and independent living prior to injury. The same cemented femoral stem was used for all patients with either a unipolar head component or a cemented all-polyethylene acetabular component. At 3 years of follow-up, the Oxford hip score in the THA patients was statistically better than those with a hemiarthroplasty, though the absolute difference was only three points. Additionally, the average walking distance for patients treated with a THA was 2.2 miles compared to 1.2 miles for those treated with a hemiarthroplasty. However, this distance in the THA group may be inflated by the upper range being reported as 25 miles, which is 20 miles over the upper range reported for this group of patients preoperatively. Quality of life, as measured by SF-36 scores, was not significantly different between the groups. Perioperative complications occurring in the first 30 days or overall mortality rate did not differ between the groups. The patients in this study were followed up at a mean 9 years after surgery [13]. Due to the high mortality rate in this patient population, 42% of patients died during the follow-up period with no difference in overall mortality between the groups. Dislocation occurred in three patients with THA, and none with hemiarthroplasty. There were revisions in one THA for stem subsidence and in four of the hemiarthroplasties (one for periprosthetic fracture and three for painful acetabular erosion).

In a study of similar design with similar inclusion criteria, Blomfeldt and colleagues randomized 120 patients to treatment with a hemiarthroplasty or THA for displaced femoral neck fractures [14]. A bipolar component was used in this study as opposed to the unipolar head in the Baker and colleagues study [12]. While shorter operative time and less blood loss were reported with hemiarthroplasty, there was no difference in complications or mortality rate. At 4-month and 1-year follow-up, the THA group had higher Harris hip scores compared to those with a hemiarthroplasty (87.2 vs. 79.4). However, the ability to perform activities of daily living, independent living status, and health-related quality of life (EQ-5_D index) were not significantly different between the groups.

A follow-up report of this group of patients was reported at 2 and 4 years by Hedbeck and colleagues [15]. The overall mortality rate for the patients in the study was 26%, but there was no difference between those with a THA or hemiarthroplasty. There continued to be no difference in complications between the groups. The higher Harris hip score in the THA group continued to be statistically significant at both 2 and 4 years, with the discrepancy increasing with time. There was a 14 point difference (89 vs. 75) in this score at 4 years. While the health-related quality of life score (EQ-5_D index) was better for patients with THA at all follow-up time points, it did not reach statistical significance until the 4-year follow-up time point.

A final randomized controlled trial assessed patients at 1 and 5 years after hemiarthroplasty or THA for displaced femoral neck fractures [16]. Their analysis revealed no significant differences in the modified Harris hip score, revision rate of the prosthesis, complication rate, or mortality. They did note an increased intraoperative blood loss, longer operative time, and hip dislocations in the total hip group compared to the hemiarthroplasty group. Based on these results, they felt hemiarthroplasty was the most appropriate treatment in this patient population.

Unipolar Versus Bipolar Hemiarthroplasty

Early hemiarthroplasty designs, such as the Austin Moore and Thompson, were monoblock components with unipolar heads. Due to concern for acetabular cartilage erosion from the interface between the metal head and articular surface, bipolar implants were developed. Theoretically, the additional articulation in a bipolar component should decrease the motion at the articular surface and thus decrease the risk of cartilage erosion.

The amount of motion that actually occurs at the inter-prosthetic interface after implantation has been brought into question. Chen and associates concluded most of the implants acted as a unipolar device, with the only motion occurring between the acetabulum and prosthetic shell [17]. Contradictory findings were reported by Gaine and associates on the same bipolar shell in which motion was also noted to be occurring at the inter-prosthetic interface [18]. This study analyzed the component motion, with simulated walking on a treadmill providing an accurate representation of in vivo performance. The inconsistency in results may be explained by methodological differences in the use of weight-bearing when examining for prosthetic motion. Since motion is likely to occur at the interface with the lowest coefficient of friction, a loaded and unloaded state would be expected to act differently.

Randomized trials comparing patients treated with either a bipolar or unipolar component have not demonstrated a clear clinical advantage for one compared to the other. Cornell and associates evaluated 48 patients (15 unipolar, 33 bipolar) at 6 months following surgery [19]. Despite the bipolar group exhibiting greater hip ROM and better performance on various walking tests, there was no difference from the unipolar group on their hip function score. Another study randomized patients over 80 years old and followed them for 2 years [20]. After controlling for possible confounding factors, there were no differences between the groups treated with either unipolar or bipolar prosthesis for pain, limp, satisfaction, or Harris hip score. Radiographic acetabular erosion was noted in three hips with a unipolar prosthesis compared to no evidence of erosion with a bipolar prosthesis, although this difference between unipolars and bipolars was not statistically significant. Davison and associates compared patients aged 65–79 years old randomized to closed reduction and internal fixation, unipolar hemiarthroplasty, and bipolar hemiarthroplasty at 2-year follow-up [21]. While the revision rate with hemiarthroplasty was significantly less than with the internal fixation group, there was no advantage to using either a unipolar or bipolar head. Finally, Raia and associates reported on 78 patients with 1-year follow-up that had been randomized to unipolar or bipolar hemiarthroplasty with no difference in complications, return to preinjury level of function, musculoskeletal functional assessment score, or SF-36 score [22].

Taken together, these results do not demonstrate a significant difference between the uses of a unipolar or bipolar hemiarthroplasty. However, the short follow-up in these studies may not be able to demonstrate the theoretical advantage of decreased cartilage wear with a bipolar articulation. Midterm follow-up studies have been done in an attempt to address this. Inngul and associates randomized 120 patients to either a unipolar or bipolar articulation with identical cemented stems and followed them for 48 months [23]. The bipolar group did demonstrate statistically significant advantage in HRQoL (EQ-5_D index score) at 48 months which was not evident at earlier follow-ups. While it was noted that the unipolar heads had more acetabular erosion compared to the bipolar heads at 12 months, by 48 months this had equalized between the groups. There was no difference in reoperation rates between the groups. Another randomized study with 5-year follow-up did not demonstrate significant differences in revision rate, ambulatory ability, return to home, nor acetabular erosion [24]. This study did note a significantly higher dislocation rate in the unipolar group compared to the bipolar group. Taken together there appears to be little evidence to support the use of unipolar versus a bipolar articulation in a hemiarthroplasty for treatment of a displaced femoral neck fracture.

Cemented Versus Uncemented Stem Fixation

The Austin Moore and Thompson hemiarthroplasty prostheses have been used for the treatment of femoral neck fractures. Both of these implants were originally designed over 50 years ago to be used without cement. However, unlike modern uncemented hip arthroplasty stems, they were not intended to attain biologic fixation at the bone–prosthesis interface. This likely resulted in postoperative hip and thigh pain from the loose implant. With the development of polymethyl methacrylate (PMMA) bone cement, surgeons began utilizing this material as a means of femoral stem fixation. PMMA in turn allowed immediate postoperative and long-term stable stem fixation.

Not surprisingly, in a randomized trial comparing a cemented Thompson stem with an uncemented Austin Moore stem, only 4/20 patients with cement fixation had pain at 18 months, compared with 13/19 treated without cement [25]. A Cochrane review analyzed both published and unpublished data from six studies that included 899 participants [26]. Nearly all of these patients were treated with either a cemented or uncemented Thompson or Austin Moore prosthesis. The Cochrane review also noted less pain and better mobility in those patients treated with cement. Additional findings included a longer operative time and lower risk of intraoperative femur fracture when using cement. The results of these studies indicate that the use of cement in the setting of an implant not designed for biologic fixation will result in superior outcomes.

Modern uncemented hip prostheses are designed for initial stability, through a press fit, followed by biologic fixation at the bone–prosthesis interface to provide long-term stability. With this type of implant, it is likely that cemented and uncemented hemiarthroplasties would have similar outcomes. Findings consistent with this supposition were found in a randomized trial of 130 patients with displaced femoral neck fracture treated with a cemented or uncemented component. At 1-year follow-up, there were similar outcomes for complication rate, mortality, and function [27].

This conclusion is further supported by a randomized trial comparing a modern hydroxyapatite-coated implant with a cemented implant [28]. Two-hundred and twenty patients over the age of 70 with displaced femoral neck fractures were randomized to bipolar hemiarthroplasty with one of the aforementioned femoral stems. At 1 year, there was no difference in complications, mortality, Harris hip score, Barthel index, or EQ-5_D score. The mean operative time for the uncemented group was 12 min shorter with slightly less blood loss. At a median 5-year follow-up, there was no difference in mortality between the treatment groups with 56% in the cemented group and 60% in the uncemented group. A significantly higher Harris hip score was reported for the uncemented group. However, the prevalence of periprosthetic femur fractures was 7.4%

in the uncemented group and 0.9% in those with cement fixation [29].

Similar findings were reported by Taylor and associates who randomized 160 patients to treatment with a modern uncemented or cemented stem. A higher number of complications were noted in the uncemented group including a higher intraoperative and postoperative periprosthetic fracture rate. There was no difference in mortality or pain between the groups. There was a trend toward better function for patients with cemented stems [30].

Evidentiary Tables and Selection of Treatment Method

Treatment goals of this patient are to allow early mobilization and return to preinjury level of function while minimizing perioperative surgical and medical complications. There is no role for nonoperative treatment in this case, as this would leave the patient bedridden with its associated complications. Additionally, there would be no chance to attain hip function similar to the patient's preoperative state.

Operative options include fracture reduction and stabilization with internal fixation or arthroplasty. In comparison with these options, reduction and internal fixation consistently result in a higher failure rate and need for revision surgery. Therefore, treatment with a hemiarthroplasty or total hip arthroplasty would be most appropriate in this case.

Studies comparing these options show mixed results. While two randomized trials favor THA [12–15] based on their outcomes, a third favors hemiarthroplasty [16].

The authors feel treatment with either a hemiarthroplasty or THA in this case would be appropriate based on the current literature.

Table 15.1 Evidentiary table: Internal fixation versus arthroplasty

Author (year)	Description	Summary of results	Level of evidence
Rogmark et al. (2002) [7]	Randomized controlled trial	450 patients randomized to internal fixation versus arthroplasty followed to 2 years. 43% failure in fixation group versus 6% in arthroplasty group. Better hip function and less pain in arthroplasty group. No difference in mortality	I
Leonardsson et al. (2010) [6]	Randomized controlled trial	10-year follow-up of Rogmark et al. 75% overall mortality with no difference between the groups. No functional difference between groups at 5 and 10 years. 45.6% failure rate for internal fixation versus 8.8% for arthroplasty	I
Parker et al. (2002) [31]	Randomized controlled trial	455 patients randomized to internal fixation versus arthroplasty. Decreased anesthesia time and blood loss with internal fixation. 40% of internal fixation patients required additional surgery versus 5% of arthroplasty patients	I
Keating et al. (2006) [8]	Randomized controlled trial	207 patients randomized to internal fixation versus arthroplasty. Fixation had 39% reoperation and lower hip function scores compared with arthroplasty. Internal fixation associated with lower initial costs, but higher reoperation rates resulted in increased late costs	I
Bhandari et al. (2003) [9]	Meta-analysis	9 trials including 1162 patients analyzed. Significantly decreased risk of revision surgery but possible increased risk in early mortality when treated with arthroplasty. Lower blood loss, infection rate, and operative time when treated with internal fixation. No difference in pain or function noted	I
Rogmark and Johnell (2006) [10]	Meta-analysis	14 trials including 2289 patients. Significant decrease in risk of revision surgery after treatment with arthroplasty. No difference in mortality at 30 days and 1 year between arthroplasty and internal fixation. Majority of studies included showed less pain and better function after treatment with arthroplasty	I
Gao et al. (2012) [11]	Meta-analysis	20 randomized controlled trials including 4508 patients. Compared with internal fixation treatment with arthroplasty resulted in fewer major complications, lower rate of reoperation, improved pain, and better function. No difference in mortality rate between the groups at 1 and 3 years	I

Table 15.2 Evidentiary table: Hemiarthroplasty versus total hip arthroplasty

Author (year)	Description	Summary of results	Level of evidence
Baker et al. (2006) [12]	Randomized controlled trial	After mean follow-up of 3 years, THA had better Oxford hip score and longer walking distance. No difference in health-related quality of life measures. Higher revision rate for hemiarthroplasty (unipolar head) group	I
Blomfeldt et al. (2007) [14]	Randomized controlled trial	120 patients randomized. Longer operative time and higher blood loss for THA. No difference in complications or mortality between groups. Statistically significant higher Harris hip scores for THA at 4 and 12 months, but not health-related quality of life measure at same time points	I
Hedbeck et al. (2011) [15]	Randomized controlled trial	2- and 4-year follow-up of Blomfeldt et al. study. Harris hip score continued to be significantly better in THA group, with an increased gap from the hemiarthroplasty group with longer follow-up. Health-related quality of life scores were statistically better for THA at 4 years	I

Table 15.3 Evidentiary table: Cemented versus uncemented

Author (year)	Description	Summary of results	Level of evidence
Emery et al. (1991) [25]	Randomized controlled trial	Compared cemented Thompson with uncemented Moore prosthesis. 13/19 patients with cemented prosthesis had no pain. 4/20 patients with uncemented prosthesis had no pain at 18 months	I
Santini et al. (2005) [32]	Randomized controlled trial	Compared an unspecified cemented with uncemented hemiarthroplasty. Follow-up at 1 year without differences in complication or radiographic outcomes	I
Figved et al. (2009) [28]	Randomized controlled trial	Compared modern cemented stem with HA-coated uncemented stem. At 1-year follow-up, there was no difference in complications, Harris hip score, or functional outcome scores	I
Parker et al. (2010) [26]	Review	Review of six studies (published and unpublished) involving 899 participants comparing cemented and uncemented hemiarthroplasty. All specified implant types were Austin Moore or Thompson. Cemented items resulted in longer operative times, reduced risk of intraoperative fracture, lower reduction of mobility score, and less residual hip pain postoperatively	I
Langslet et al. (2014) [29]	Randomized controlled trial	Hips randomized to cemented (112) and uncemented (108) hip hemiarthroplasty. Harris hip scores at 5 years higher in the uncemented group than in the cemented group (86.2 vs. 76.3). Postoperative periprosthetic femur fractures were 7.4% in the uncemented group and 0.9% in the cemented group	I

See Tables 15.1, 15.2, and 15.3 for evidentiary tables for internal fixation versus arthroplasty (Table 15.1 [6–11, 31]), for hemiarthroplasty versus total hip arthroplasty (Table 15.2 [12, 14, 15]), and cemented versus uncemented (Table 15.3 [25, 26, 28, 29, 32]).

Predicting Outcomes

Three outcomes relevant to treatment of elderly patients with femoral neck fractures are mortality, return to preinjury level of function, and return to preinjury quality of life. These outcomes are somewhat dependent on preoperative level of function and medical comorbidities which can vary widely in this population. The patient presented in this case is an independent community ambulator, the highest functional level for this type of patient.

Treatment method does not seem to have an effect on mortality rate. While one meta-analysis noted a trend toward increased mortality for arthroplasty compared to internal fixation in the first 4 months after surgery [9], a subsequent meta-analysis did not find a mortality difference at 30 days and 1 year postoperatively [10]. In these two studies, the mortality rate at 1 year ranged from 20 to 23% following treatment of a displaced femoral neck fracture. Treatment with an arthroplasty does not seem to improve survival over other forms of treatment.

After surgery for femoral neck fracture, patients infrequently recover their preoperative hip function or quality of life. This is true regardless of treatment method, including total hip replacement as presented in this case. At an average follow-up of 3 years, patients treated with THA had significantly lower Oxford hip scores and SF-36 scores, compared to preoperative levels [12]. Another study noted that patients treated with THA did not attain their preinjury EQ-5_D index score at 4-year follow-up [15]. This is in contrast to patients treated with THA for symptomatic osteoarthritis of the hip, which generally have improved hip function and quality of life compared to their preoperative state. In these patients, hip replacement is an improvement over their chronically diseased, painful hip. Comparatively, patients with a hip fracture may have had a "normal" hip prior to their injury, and a THA may not achieve this same level of function. The result of this may be reflected in patient satisfaction discrepancy that is anecdotally noted by the authors in postoperative follow-up.

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16 Intertrochanteric Femur Fractures

Hassan R. Mir

BB: A 79-Year-Old Male with Hip Pain

Case Presentation

BB is a 79-year-old male who presents to the emergency department with a chief complaint of right hip pain after slipping on a rug and falling. He is transferred to the emergency department via EMS. On presentation, he demonstrates a GCS of 15 and denies any loss of consciousness. On primary survey, his airway is patent, and he is hemodynamically stable. On secondary survey, he demonstrates severe pain with passive range of motion of the right hip. His secondary survey is otherwise negative.

On physical exam, the patient is a healthy-appearing male in no acute distress. He is hemodynamically stable, awake, and alert. The right foot appears externally rotated compared to the left. The patient has pain with passive range of motion of the right hip. There are no open wounds, the dorsalis pedis and posterior tibialis pulses are palpable, and sensation to light touch is intact in all dermatomal distributions.

Radiographs of the right hip are demonstrated in Fig. 16.1a, b.

H. R. Mir (✉)
Florida Orthopedic Institute,
University of South Florida, Tampa, FL, USA
e-mail: hmir@floridaortho.com

Interpretation of Clinical Presentation

The patient's history, exam, and radiographic findings are consistent with a right intertrochanteric femur fracture. Intertrochanteric fractures are extracapsular fractures of the proximal femur involving the region between the greater and lesser trochanter.

The intertrochanteric metaphyseal region has an abundant blood supply, which is what differentiates injuries to this area from femoral neck fractures with regard to fracture union and osteonecrosis [1]. Intertrochanteric fractures are among the most common orthopedic injuries in the geriatric population and are increasing in frequency, as the percentage of the world population that is elderly is rising.

BB is 79 years old, so a detailed history and physical examination are important to ensure optimal care for his fracture and overall condition. Many geriatric patients with intertrochanteric fractures have medical comorbidities that can be addressed by comanagement with medical services in order to optimize preoperative status, perioperative care, and long-term outcomes [2–6]. Patients with major clinical abnormalities should have them corrected prior to surgery, but patients with minor abnormalities may proceed to surgery with attention to these medical problems perioperatively [3]. Preoperative cardiac testing has been shown to

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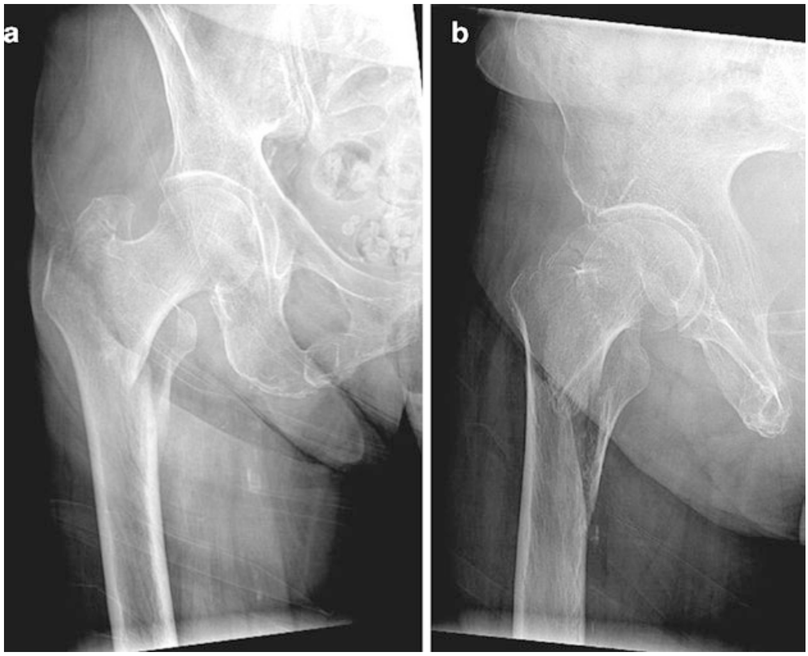

Fig. 16.1 (**a**) AP radiograph of the hip. (**b**) Lateral radiograph of the hip

be of questionable benefit, as it rarely influences medical management but greatly increases costs and delays to surgery [7]. However, in patients with aortic stenosis (AS), the severity of disease can affect the surgical anesthetic choice, with general anesthesia being the preferred method for moderate to severe AS to maintain autonomic responses to hypovolemia. It is important to evaluate the geriatric patient's preoperative functional status and social support system, as they are factors that may play an important role in predicting long-term outcomes [8, 9]. During the preoperative period, skin traction in patients with hip fractures has been shown not to provide significantly more pain relief than simple pillow placement under the injured extremity [10].

Radiographs should include an anteroposterior (AP) view of the pelvis, a full-length AP, and cross table lateral films of the femur. The pelvic radiograph can help with preoperative planning to restore proper alignment of the femoral neck-shaft angle and greater trochanter to femoral head height relationship, with contralateral comparison. Full-length radiographs of the femur can help to assess for deformity of the femoral shaft, such as excessive bowing, and to evaluate for distal implants from prior knee arthroplasty or trauma. Most of the classification systems for intertrochanteric fractures have poor reliability and reproducibility [1]. A simplified system to aid in evaluating treatment algorithms when assessing the literature is based on fracture stability, which is related to the condition of the posteromedial cortex. Intertrochanteric fractures are considered unstable with comminution of the posteromedial cortex, reverse obliquity, and subtrochanteric extension. Assessment of the integrity of the lateral wall of the greater trochanter is also important, as it provides the necessary lateral buttress for controlled collapse during fracture healing when using a side-plate-based device [11]. Intertrochanteric femur fractures are considered stable in the absence of involvement of the posteromedial cortex and the greater trochanteric lateral wall. The radiographs of BB appear to show involvement of the posteromedial cortex.

Declaration of Specific Diagnosis

BB is a 79-year-old male who presents with an unstable right intertrochanteric femur fracture.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Medical evaluation and perioperative management
2. Early surgical stabilization and mobilization
3. Fracture union in acceptable alignment
4. Return of function
5. Avoidance of future fractures

Treatment options include:
Conservative

1. Nonoperative treatment

Surgical

1. Timing of surgery
2. Choice of anesthesia
3. External fixation
4. Arthroplasty
5. Extramedullary fixation
6. Intramedullary fixation

Evaluation of the Literature

In order to identify relevant publications on intertrochanteric femur fractures, a PubMed search was performed. Keywords included "intertrochanteric femur fracture," and the search was limited to human clinical trials and meta-analyses in the literature from 1966 to 2011. This search identified 2311 abstracts that were reviewed. From this search, 115 articles were read, reference lists were reviewed, and 45 articles were selected based on highest level of evidence and for citation in accordance to reference limitations for chapters in this text. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

The following discussion explores the relevant literature in order to determine the most optimal treatment for BB.

Conservative/Nonoperative Treatment

Most patients with intertrochanteric femur fractures are treated surgically, with nonsurgical treatment usually reserved for patients with comorbidities that place them at unacceptably high risk from anesthesia or surgery [12]. Mortality from nonsurgical treatment typically results from cardiopulmonary complications, thromboembolism, and sepsis. A meta-analysis by Parker and colleagues in 2000 of four randomized trials including 402 patients found that surgical treatment results in better reduction, earlier mobilization, lower perioperative morbidity, decreased hospital stay, and increased independence over nonoperative management.

Surgical Treatment

Timing of Surgery

The time period between diagnosis of an intertrochanteric fracture and definitive surgical fixation can have an effect on patient outcomes, as reported in multiple studies [13–17]. In their 2009 meta-analysis of 52 studies involving 291,413 patients, Khan and colleagues concluded that surgery within 48 h of admission reduces hospital stay and may also reduce complications and mortality [15]. In a 2010 study by Holt and colleagues, data on 4284 patients were analyzed and showed that postponement of surgery without correction of a medical abnormality was associated with a significantly lower 30-day adjusted survival [14]. Simunovic and colleagues published a meta-analysis of 16 studies involving 13,478 patients showing that earlier surgery was associated with lower risk of death, postoperative pneumonia, and pressure sores among elderly patients with hip fractures [17]. In summary, the referenced literature suggests that operative fixation within 48 h after admission may decrease the odds of 30-day all-cause mortality and of 1-year all-cause mortality, decrease hospital length of stay, lower rates of postoperative pneumonia, lower rates of pressure sores, and increase the ability to return to independent living.

Choice of Anesthesia

The decision between neuroaxial versus general anesthesia has been examined by several authors in randomized trials and large meta-analyses [18, 19]. In 2010, Luger and colleagues published their analysis of 56 studies including 18,715 patients comparing neuroaxial and general anesthesia in geriatric hip fracture patients [18]. Their findings showed that spinal anesthesia may be associated with significantly reduced early mortality, a lower incidence of deep vein thrombosis, less delirium, a tendency to fewer myocardial infarctions, fewer cases of pneumonia, fatal pulmonary embolism, and postoperative hypoxia but that definitive conclusions could not be made. General anesthesia had the advantages of having a lower incidence of hypotension and a tendency toward fewer cerebrovascular accidents compared to neuroaxial anesthesia. In 2016, Guay and colleagues performed a Cochrane Database review of 31 trials involving 3231 patients and comparing regional and spinal anesthesia for geriatric hip fracture patients [19]. They did not find a difference between the two techniques, except for deep venous thrombosis in the absence of potent thromboprophylaxis. The existing data from the referenced literature suggest that the available evidence does not permit a definitive conclusion to be drawn for mortality or other outcomes. The overall therapeutic approach in hip fracture care should be determined with multidisciplinary involvement from the orthopedic surgeon, the geriatrician, and the anesthesiologist.

External Fixation

The use of external fixation as definitive treatment for intertrochanteric fractures was performed in the 1950s but was abandoned due to the high prevalence of pin loosening, infection, and mechanical failure of the fixator [20, 21]. In a 2005 study, Moroni and associates conducted a prospective randomized study of 40 patients in whom an osteoporotic pertrochanteric fracture was treated with either a dynamic hip screw or an external fixator secured with four hydroxyapatite-coated pins. The external fixation group had shorter operative time, no postoperative transfusions, less pain, less varus collapse at 6 months, and equal Harris hip scores compared to the sliding hip screw group. Patients were full weight bearing on postoperative day 1, and fixators were removed at 3 months. Other recent reports in the European literature have shown similar results [20]. The pertrochanteric fixator with hydroxyapatite-coated pins may be a viable alternative for treating high-risk, elderly patients, although more high-quality evidence from larger trials is necessary [21].

Arthroplasty

Prosthetic hip replacement generally has not been considered a primary treatment option for intertrochanteric fractures [1, 22, 23]. Unlike femoral neck fractures, which retain some of the femoral neck in addition to the abductor mechanism, intertrochanteric fractures involve more distal femoral bone, and often the greater trochanter and the abductors are not attached to the proximal femur. Prosthetic replacement for intertrochanteric fractures typically requires a more complex surgical procedure, with potentially higher morbidity and postoperative transfusion rates. Parker and Handoll reported in a 2006 Cochrane Database review on two randomized controlled trials involving 148 patients that there was insufficient evidence to determine whether replacement arthroplasty has any advantage over internal fixation for extracapsular hip fractures [22]. In 2005, Kim and associates performed a prospective randomized study of unstable intertrochanteric fractures in 58 elderly patients in which long-stem cementless calcar-replacement hemiarthroplasty was compared with a cephalomedullary nail, and the results showed that surgical time, blood loss, need for blood transfusion, and mortality rates were all significantly lower in the nail group [24]. However, there were no significant differences between the two groups in terms of functional outcomes, hospital stay, time to weight bearing, and risk of complications. Dong and associates published a meta-analysis of seven studies in 2015 and concluded that internal fixation for the treatment of intertrochanteric fractures is superior to hip replacement (containing FHR or THA) with regard to total complication rate [23].

Based on the limited available evidence, it is the author's opinion (level V evidence) that arthroplasty should be reserved for intertrochanteric hip fractures in patients with preexisting symptomatic degenerative arthritis, those in whom internal fixation is not expected to be successful because of fracture comminution or bone quality, and patients who require salvage for failed internal fixation.

Extramedullary Versus Intramedullary Fixation

Stable intertrochanteric fractures have shown equal outcomes with extramedullary (plate-and-screw) implants versus intramedullary devices [25]. The most recent Cochrane review of 43 trials in 2010 on surgical fixation of intertrochanteric femur fractures concluded that the sliding hip screw is superior given the lower rate of complications with that device; however, as noted by the authors, many of the papers contained within the meta-analysis included "first-generation" intramedullary devices with older implantation techniques. Bhandari and associates in 2009 performed a meta-analysis of 25 trials to account for the improvements in intramedullary implant design and surgical technique, and their findings suggested that previous concerns about increased femoral shaft fracture risk with intramedullary nails have been resolved [26]. Their study highlighted the fact that earlier meta-analyses and randomized trials should be interpreted with caution in light of more recent evidence.

Unstable intertrochanteric fractures should benefit from an intramedullary device based on biomechanical concepts that require competence of the posteromedial cortex and the lateral trochanteric wall to prevent excessive collapse with extramedullary devices. There are extramedullary devices available with modifications that extend proximally to support the lateral trochanteric wall during fracture compression and healing of unstable intertrochanteric fractures. A review of the orthopedic oral board database from 1999 to 2006 noted that a dramatic change from 3% to 67% in surgeon preference for intramedullary fixation in the treatment of intertrochanteric fractures had occurred among young orthopedic surgeons [27]. According to the 2010 Cochrane Database review, there was no overwhelming clinical evidence to prove this recommendation in the available literature at that time since stable and unstable patterns had not been evaluated separately in most studies [25]. However, there have subsequently been a growing number of studies that show benefits for intramedullary implants for unstable intertrochanteric fractures. In 2005, Pajarinen and associates published their results on a prospective randomized trial involving 108 patients with intertrochanteric fractures and found that those fixed with an intramedullary device had regained their walking ability significantly more often by the 4-month visit than those treated with an extramedullary device [28]. Guerra and associates reported in their 2014 prospective randomized trial that dynamic hip screw-treated patients exhibited significant loss of function in the first 6 months after surgery, which did not occur in the intramedullary nail treated group [29]. In 2015, Sanders and associates published a prospective randomized trial of 167 patients that found less femoral neck shortening with intramedullary fixation (avg. 0.2 cm) of unstable intertrochanteric fractures compared to extramedullary fixation (avg. 1.0 cm) [30]. Bretherton and associates published data from a randomized controlled trial of 538 patients in 2016 that found unstable hip fractures treated with a sliding hip screw undergo more femoral medialization which correlates with worse functional outcomes than intramedullary nails [31]. In a recent prospective randomized trial of 249 patients comparing a novel intramedullary device (InterTAN) versus a sliding hip screw, it was concluded that while most patients with intertrochanteric femur fractures can expect similar functional results whether treated with an intramedullary or extramedullary device, that active and functional patients have an improved outcome when the InterTAN is used to treat their unstable intertrochanteric fracture [32].

In the Cochrane review from 2014, there was limited evidence from the randomized trials undertaken to date to determine whether there are important differences in outcome between different designs of intramedullary nails used in treating extracapsular hip fractures [33]. There is inadequate evidence to support the use of older techniques such as displacement osteotomy for internal fixation of a trochanteric hip fracture or multiple other technique modifications, such as cement augmentation or distal venting hole creation as examined in a meta-analysis by Parker and associates in 2009 [34]. Several recent studies have found no differences between modern short nails and long nails with regard to union and complication rates [35]. The surgeon needs to consider the fracture configuration and related factors, including whether osteoporosis is present and the cost and risk of revision surgery, when selecting the appropriate nail length. There is biomechanical support for the use of distal interlocking screws in unstable fracture patterns to increase torsional and rotational stiffness, especially since the maximal torsional load to failure for an unlocked nail is within the functional range of rotational loads experienced at the hip for an average adult [36]. The importance of surgical technique with tip-apex distance (TAD) as a predictor of lag screw cutout for both extramedullary and intramedullary devices was demonstrated by Baumgartner and associates in 1995, with no cutouts occurring in the 120 out of 198 cases in his series with <25 mm TAD [37]. In 2013, Rubio-Avila and coworkers published a meta-analysis of 17 studies that confirmed TAD as an important concept in relation to cutout failure of hip fracture fixation surgery [38]. Regardless of the implant chosen, it is important that an accurate reduction and stability be achieved with appropriately positioned fixation to maximize the likelihood of a successful outcome.

Literature Inconsistencies

As can be seen from the preceding sections, areas of controversy exist in the literature with regard to surgical timing, anesthetic choice, and method of fixation for intertrochanteric femur fractures.

The majority of the evidence is from large meta-analyses and systematic reviews of prospective randomized trials; however, much of the older data for fixation do not separate old and modern implant designs and techniques or stable versus unstable fracture patterns.

Evidentiary Table and Selection of Treatment Method

The studies that influence the treatment of BB are noted in Table 16.1 [6, 15, 19, 26, 31, 38]. Based on the literature, the recommended treatment in this case of an intertrochanteric femur fracture in a geriatric patient is early surgical fixation with medical comanagement. Unstable intertrochanteric fractures benefit from intramedullary nail fixation with increasing clinical evidence.

Definitive Treatment Plan

The operative goal in treatment of intertrochanteric femur fractures is to obtain and maintain anatomic alignment with stable fixation to allow early patient mobilization. Intertrochanteric femur fractures are typically operated on as soon as the patient's medical condition allows but in an urgent rather than emergent fashion. An intramedullary nail with fixation inserted into the femoral head (cephalomedullary fixation) is used for unstable fracture patterns and can usually be performed through small incisions with fluoroscopic guidance for nail, cephalomedullary, and interlocking screw placement. Most intertrochanteric fractures are fairly amenable to closed reduction techniques with the use of a fracture table and external methods alone, while comminuted fractures and those with reverse obliquity or subtrochanteric extension are more challenging to align and stabilize and may require the use of bone hooks, clamps, or percutaneous Schanz pins.

The patient is placed supine on a radiolucent fracture table with the legs placed in a scissored position. A well-padded perineal post is used. Traction is applied, and the leg is internally

Table 16.1 Evidentiary table: A summary of the level of evidence for fixation of intertrochanteric fractures

Author (year)	Description	Summary of results	Level of evidence
Bhandari et al. (2009) [26]	Meta-analysis	In a review of 25 randomized trials, authors found that previous concerns about increased risk with cephalomedullary nails have been resolved with modern implant design	I
Khan et al. (2009) [15]	Systematic review	52 studies involving 291,413 patients were reviewed. Early surgery (<48 h) after a hip fracture reduces hospital stay, complications, and mortality	I
Kammerlander et al. (2010) [6]	Systematic review	21 studies were reviewed. Integrated orthogeriatric care showed the lowest in-hospital mortality rate (1.14%), the lowest length of stay (7.39 days), and the lowest mean time to surgery (1.43 days)	I
Rubio-Avila et al. (2013) [38]	Systematic review	In a review of 17 studies, patients with TAD >25 mm had a significantly greater risk of cutout than patients with TAD <25 mm (RR = 12.71)	I
Guay et al. (2016) [19]	Systematic review	31 studies were reviewed, covering 3231 patients. There is no difference for mortality or other outcomes with spinal versus general anesthesia	I
Bretherton et al. (2016) [31]	Randomized controlled trial	Trial of 538 patients that found unstable hip fractures treated with a sliding hip screw undergo more femoral medialization which correlates with worse functional outcomes than intramedullary nails	I

rotated in most intertrochanteric fracture patterns for rotational alignment of the proximal and distal segments. Fluoroscopic imaging is used in the anteroposterior (AP) view to ensure proper alignment of the femoral neck-shaft angle. The preoperative AP pelvis radiograph can be used for guidance to obtain proper alignment by comparison with the contralateral hip for neck-shaft alignment and evaluation of the relationship between the tip of the greater trochanter and the center of the femoral head. On the lateral fluoroscopic view, the femoral head, neck, and shaft are aligned collinearly by matching the patient's anteversion with the arc of the C-arm, with care to assure that no posterior sag of the fracture or malrotation exists. Correction of posterior sag sometimes requires the use of a crutch under the drapes or sterile methods of external or internal support intraoperatively to provide an anteriorly directed lifting force to correct the deformity during reaming, nail, and lag screw placement.

After the patient is prepped and draped in a normal sterile fashion, a 3-cm incision is made 3 cm proximal to the tip of the greater trochanter, with sharp dissection through the gluteal fascia. Most modern cephalomedullary nails are designed with a proximal lateral bend for trochanteric entry. A guide pin or awl is used to obtain the appropriate starting point, which is medial to the tip of the trochanter on the AP view. On the lateral view, the guide pin should be centered on the femoral neck, which usually places the pin along the level of the junction of the anterior one-third and posterior two-thirds of the femoral shaft, to ensure that the lag screw will be placed centrally into the femoral head. Anatomic fracture alignment should be obtained prior to proximal femoral preparation with the entry reamer in order to avoid malreduction with nail placement.

Long intramedullary nails with distal interlocking screws are chosen by some surgeons for geriatric patients with intertrochanteric fractures to provide stabilization throughout the length of the femur, similar to the concept applied when dealing with pathologic fractures. A long ball-tipped guide rod is placed into the distal femur with biplanar fluoroscopic confirmation of central positioning. This step is important to avoid distal anterior cortical penetration or impingement in patients with excessive femoral bow, as well as malalignment of the fracture proximally in the AP or lateral plane with the placement of a long intramedullary nail. In patients with severe deformity, a short nail or a side-plate-based device should be considered depending on the fracture pattern. The femoral shaft sometimes needs to be reamed in patients with good bone quality, followed by placement of the nail. The nail is initially inserted with its anterior bow turned laterally to match the trajectory needed to navigate the proximal femur and avoid fracture of the medial cortex in the subtrochanteric area. Nail placement should be a gentle process in the geriatric population, and if a great deal of force with a mallet is required, then careful assessment should be done to assess for a bow mismatch between the implant and the femur. The neck-shaft alignment should be carefully observed during nail insertion, as displacement can occur due to implant bulk proximally, leading to either varus displacement or valgus displacement with calcar gapping. Potential solutions require the removal of the nail, reduction of the deformity, and re-reaming of the proximal femur to ensure adequate bone removal in the appropriate area. The use of reduction clamps and bone hooks may be necessary to prevent the deformity from recurring with reintroduction of the nail.

The guide pin for the lag screw is placed through the appropriate sleeve via a second lateral incision. A second point of fixation with either an additional screw or provisional pin is performed to avoid malrotation of the head–neck segment with lag screw insertion and for the second screw to provide rotational stability during patient mobilization until bony union. A cannulated reamer is used for creation of the lag screw path, and in patients with good bone quality, a tap may be necessary. The lag screw is placed with careful attention to obtaining a TAD of less than 25 mm on combined AP and lateral views. The traction is released from the fracture table to avoid fracture fixation in distraction, and the fracture is compressed manually with the appropriate implant-specific instrumentation. The set screw is inserted to provide for controlled collapse with rotational stability. The nail is locked distally with a screw through a stab incision using fluoroscopic technique. One or two distal screws are used depending on the fracture pattern and risk for axial and rotational instability. The wounds are closed in a standard layered fashion. The patient is permitted full weight bearing with two-arm support. Geriatric patients are medically comanaged during the perioperative period, with careful attention to their comorbidities, deep venous thrombosis prophylaxis with mechanical and chemical agents, and avoidance of delirium. Adequate follow-up is ensured for evaluation and treatment of osteoporosis and prevention of future fragility fractures.

Predicting Long-Term Outcomes

In studies conducted by Hirose and coworkers in 2010 of 421 patients followed for 1 year and Ekstrom and coworkers in 2009 of 148 patients followed for 2 years, the most predictive factors for functional outcomes following operative treatment of intertrochanteric hip fractures were preinjury function, age, and dementia [8, 9]. In Ekstrom's study, many patients with stable fracture patterns were able to regain their preinjury walking ability (55%) and their pre-fracture level of daily living function (66%); however, a considerable number of patients experienced deterioration in these areas of one or more functional levels [8]. In a 2010 systematic review by Roth and coworkers, age, gender, comorbid conditions, pre-fracture functional abilities, and fracture type had an impact on the outcome regarding ambulation, activities of daily living, and quality of life. Unstable fracture patterns tended to have worse early functional outcomes that equalized over time with stable patterns [5]. The existing evidence clearly demonstrates that mobility is affected in patients like BB in the long term. Strategies to improve mobility include gait retraining, various forms of exercise, and muscle stimulation [39].

Older adults have a five- to eightfold increased risk for all-cause mortality during the first 3 months after hip fracture, and this excess annual mortality persists over multiple years for both women and men; but at any given age, excess annual mortality after hip fracture is higher in men than in women [40, 41]. Multidisciplinary treatment for patients with intertrochanteric fractures, with comanagement by orthopedic and medical or geriatric services in order to optimize perioperative care, improves the outcomes of geriatric fracture patients [2–6]. Comprehensive care models have shown improvements in 30-day mortality, 1-year mortality, and early and late mobilization following geriatric hip fractures [42–44]. Orthopedic surgeon involvement with medical issues can improve outcomes for geriatric patients with regard to problems, such as fall prevention, nutrition, and osteoporosis screening and treatment [5, 6, 45].

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17 Femoral Neck Fractures in the Young Patient

Cory A. Collinge

MW: A 22-Year-Old Female with a Pauwels' III Right Femoral Neck Fracture

Case Presentation

MW is a 22-year-old woman (BMI 22) who presents as an unrestrained driver in an automobile crash where she rear-ended a semitruck. She had a brief loss of consciousness but no other deficits. She presents to the emergency department with complaints of right hip and thigh pain.

Past medical history is noncontributory. There are no allergies and no medications taken at home, and the review of systems is otherwise negative.

The patient is awake and conversive, is breathing easily, and remains hemodynamically stable. She has a traction splint on the right lower extremity. The right thigh is moderately swollen but soft. The skin around the thigh is intact. The foot moves up and down, and there is a strong DP pulse. Plain radiographs of the pelvis and right femur show a displaced, vertically oriented (Pauwels' III) right femoral neck fracture (Fig. 17.1a). CT scan of the pelvis including the right hip shows typical fracture configuration and deformity (Fig. 17.1b, c).

C. A. Collinge (✉)
Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA
e-mail: cory.a.collinge@vanderbilt.edu

Interpretation of Clinical Presentation

The fracture pattern seen in young adults is often very different than those seen in the elderly. In the elderly, these fractures are often a result of low energy resulting in subcapital or impacted transverse fractures, while in the younger population the fracture pattern is often basicervical or a more distal neck fracture that is more vertical and is more biomechanically unstable as seen in this case [1, 2].

Findings for MW are consistent with a displaced Pauwels' III (vertical) right femoral neck fracture with an associated right femoral shaft fracture. In order to properly treat these fractures, one must understand the spectrum of the Pauwels' classification. Pauwels' type I fractures are more stable than Pauwels' III fractures due to the intrinsic compressive forces that predominate. Pauwels' III fractures are inherently unstable as the fracture is more vertically oriented, resulting in increased shear force, varus moment, and instability [3]. Determining the classification of the fracture is important as Pauwels' type III fractures have been shown to contribute to adverse effects of fracture fixation and union rates, but not rates of avascular necrosis [4].

In this younger population with normal bone, the mechanism of injury is axial loading with the leg in an abducted position [5]. With or without associated femoral shaft fractures, vertical neck fractures in young adults are typically cased via high-energy trauma. The patient should be

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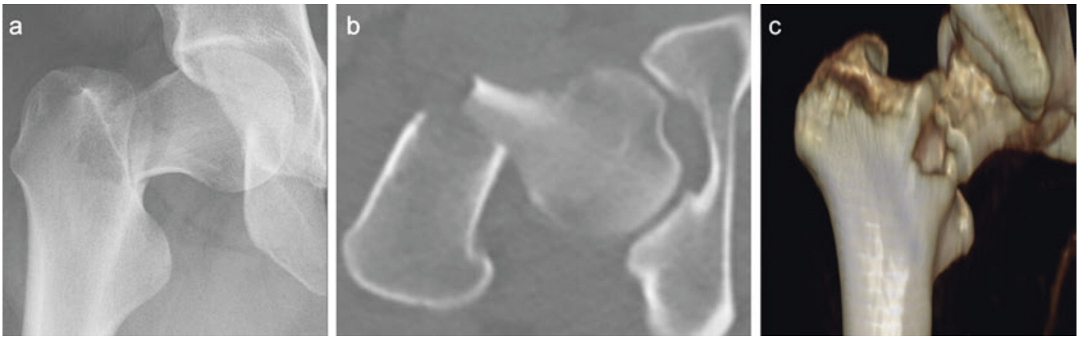

Fig. 17.1 (**a**) AP radiograph of the right hip. (**b**, **c**) CT scan of the pelvis including the right hip

assessed and treated accordingly. ATLS and institution-specific trauma protocols should be followed.

Patients with these injuries often present with a shortened, flexed, and externally rotated limb [6]. The orthopedic consultant should assess the patient for other associated injuries; specific to this case, one should evaluate for ipsilateral knee ligament or other injuries to the leg, foot and ankle, or acetabulum. Almost half of femoral neck fractures in the young adult have associated femoral shaft fractures but often include ipsilateral lower extremity trauma including knee injuries, such as patella fractures, distal femur fractures, or others. In the case of a femoral shaft fracture, one should evaluate for a femoral neck fracture. In this scenario, the diagnosis of a femoral neck fracture will be missed in up to 30% of cases [7]. In regard to imaging, AP and lateral radiographs should be taken of the entire femur [6]. CT scan of the pelvis is often performed on these patients as they are involved in high-energy mechanism. These should be checked for acetabular fracture, for femoral head fracture, and for more information about the femoral neck fracture, i.e., fracture orientation and presence of comminution. A traction view of the femoral neck is also very helpful, which can be done by getting an AP hip radiograph while applying longitudinal traction and internal rotation of the leg. With these studies, the surgeon can proceed to surgery with a good sense that they are dealing with a typical vertical neck fracture and that the bone quality is appropriate for repair (and not replacement).

Alternatively, surgeons treating femoral shaft fractures should be highly suspicious that a femoral neck fracture may be present. Occult femoral neck fractures can exist in this setting, with up to 10% or more of these being missed [6]. The outcomes of a missed femoral neck fracture in a young adult are potentially catastrophic. It is highly recommended that patients with a femoral shaft fracture that have a CT scan, have it checked for neck injury, and that radiographs of the proximal femur be carefully scrutinized intraoperatively for occult fracture.

Declaration of Specific Diagnosis

MW is a 22-year-old woman with a displaced Pauwels' III right femoral neck fracture.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Rule out other traumatic injuries.
2. Anatomically reduce the femoral neck fracture.
3. Provide stable mechanical fixation for the femoral neck fracture.
4. Minimize complications of the femoral neck fracture, as possible.

Treatment options:
Nonoperative:

1. The patient in extremis only (apply skeletal traction +/− Ex Fix, damage control)

Operative:

1. Fixation with sliding hip screw + anti-rotation screw.
2. Fixation with three cannulated screws (two parallel, one off axis).
3. Fixation with three parallel cannulated screws may be contraindicated in a Pauwels' III vertical fracture (deficient medial calcar buttress) as the inferior screw relies on a calcar buttress to prevent varus collapse.
4. Addition of medial antiglide plate.
5. Open reduction via Smith-Petersen (vs. closed reduction vs. open reduction via Watson-Jones approach).

Evaluation of the Literature

To identify relevant publications on femoral neck fractures, electronic Medline and PubMed searches were performed. Keywords included the following: "femoral neck fracture" and "fracture fixation." All searches were limited to publications from January 1, 1975 until 2017, English language, human subjects, and chronological adults (> 18 years of age). This search identified 340 abstracts that were reviewed. From this, 100 publications were read and their reference lists were reviewed.

Detailed Review of Pertinent Articles

The treatment of displaced femoral neck fractures in healthy young adults remains an unsolved challenge in orthopedic surgery. These injuries typically result from high-energy mechanisms causing a vertically oriented fracture through the femoral neck. Pauwels described this injury and classified these fractures according to the verticality of the fracture, recognizing the problem nature of the injury pattern. The type I injury is less than 30° Pauwels' angle, the type II angle is 30–50°, and the type III angles are greater than 50° (Fig. 17.1c) [8]. These factors contribute to the difficulty of obtaining alignment and construct stability to resist vertical shear forces around the hip, and the risk of complications increase as the fracture's angle of inclination increases despite a number of fixation strategies. Complications associated with femoral neck fractures in young patients are frequent (20–60%) and often catastrophic, including nonunion (often associated with failed fixation), avascular necrosis, and malunion [5, 9–11]. A number of ongoing controversies exist regarding these injuries including open vs. closed reduction, surgical approach, optimal fixation construct, and where the line should be drawn between surgical repair vs. replacement.

Improvements in the quality of computed tomography (CT) have allowed for a more complete morphological description of the Pauwels' III femoral neck fracture. Collinge and coworkers [12] reported further details of fracture orientation and comminution of femoral neck fractures in adults <50 years old. The coronal (vertical) fracture angled 60° and the axial fracture plane obliquity averaged 24° with relative deficiency of the posterior neck. The authors also identified major femoral neck comminution (>1.5 cm) in 96% of cases, with most located in the inferior (94%) and posterior (84%) neck regions. The authors excluded non-displaced fractures and those associated with femur and acetabular injury as those injuries may present with different morphology. Fracture displacement and deformity in these injuries seem intuitive but do not appear to be well addressed in the literature.

Surgical Management

Surgical Timing

For many years, displaced femoral neck fractures were managed on an emergent basis with the aim of preserving blood flow to the femoral head. Early studies indicated that early fixation may decrease osteonecrosis and increase functional outcome [9]. However, subsequent studies specifically evaluating this factor have found little or no difference in osteonecrosis rates or outcomes between early and delayed time to fixation [13–15]. For example, Pauyo and coworkers [16] discussed a study by Rasik and colleagues in which Rasik reported on 92 patients with femoral neck fractures and found no difference in osteonecrosis rates comparing treatment within 6 h post-injury and delayed treatment at 48 h post-injury. Given the evidence regarding outcomes of emergent vs. "early" surgery for this injury, most experts currently recommend treating displaced femoral neck fractures on an early basis when the patient is stable and appropriate resources are mobilized to allow for a quality surgical experience [16, 17].

Reduction

Reduction can be performed via open (ORIF) or closed (CRIF) methods. A multicenter retrospective cohort study was performed in young adults with OTA 31-B2 or 31-B3 fractures with a minimum 6 month follow-up. Patients were either treated by ORIF or CRIF. Two hundred thirty-nine patients (126 ORIF and 113 CRIF) were included. In this study, patients who underwent CRIF were older, had more comorbidities, and were more likely to have sustained an OTA type B3 fractures, while ORIF patients were more likely to have Pauwels' type III injuries and concomitant femoral shaft fractures. There was no significant difference in total reoperation rate between ORIF (47 [37.3%]) and CRIF (31 [27.4%], $P = 0.14$), although ORIF patients had a significantly higher incidence of reoperation due to nonunion compared to CRIF patients (16.7% vs. 5.3%, $P = 0.010$). Through a multivariable logistic model, ORIF was associated with a two-fold increase in reoperation rate versus CRIF (odds ratio [OR] 2.13, 95% CI 1.07–4.23, $P = 0.02$ [18]). Amid modifiable factors, the quality of fracture reduction has been shown to be among the most consistent predictors of successful treatment [10, 11, 17]. Anatomical reduction of the fracture, aside from restoring the normal anatomy, should allow for maximal stability of the fixation construct. For example, many of these fractures have an apical fracture spike that, if anatomically reduced, may dramatically increase the stability of the repair construct. Open approach to the hip also allows the surgeon to apply supplemental fixation into the neck area that may be desirable in some cases [19]. Finally, open approach provides decompression of the intracapsular hematoma, which if left untreated may increase the risk for AVN from increased intracapsular pressure preventing adequate blood flow to the femoral head [9].

Open surgical fixation of a femoral neck fracture may be performed on a flat radiolucent table or on a fracture table. A flat radiolucent table allows for greater freedom to manipulate the limb that may aid with exposure and reduction. There are two commonly used surgical approaches to the femoral neck, a direct anterior approach as described by Smith-Petersen (or Heuter) and an anterolateral approach as described by Watson-Jones. The modified Smith-Petersen approach allows for excellent direct visualization of the femoral neck and the typical vertical fracture line which typically exits in the anteroinferior region of the femoral neck to the level of the lesser trochanter [13], reapproximating the fracture apex at the calcar. The disadvantage of the Smith-Petersen approach is that traditional implants must still be applied through a lateral incision; thus a second incision is necessary for fixation. Through the Watson-Jones approach, the entire operation can be performed through the anterolateral window, although access for reduction and instrumentation of the neck is limited, especially in muscular or obese patients.

Fixation

For optimal treatment of vertical femoral neck fractures, fixation must be able to resist the high shear forces across the fracture with hip motion, weight-bearing, and muscle tone. Several fracture fixation constructs have been recommended for vertical femoral neck fractures; although, none of these constructs have been found to optimally resist the shearing forces across the hip with this fracture pattern. Shortening with resultant malunion and loss of fixation and nonunion have been common problems. Three parallel, cannulated lag screws placed along the axis of the femoral neck have been frequently described [19]. These screws, however, while optimally applied perpendicular to most femoral neck fractures (e.g., Pauwels' type I), are applied obliquely in relation to more vertically oriented factures (e.g., Pauwels' II and III); thus instability vs. shearing is possible. Also, the mechanical advantage of placing a screw along the shaft-neck's inferior cortex or "calcar" as in repairing a typical osteoporotic neck fracture is lost, as this part of the fracture is attached to the head fragment in the vertical fracture pattern (Fig. 17.1a–c) [12]. Clinical failure rates using parallel screws appear greater than the SHS in a number of studies and have been shown to have the worst performance compared to other methods in mechanical testing using a "younger" fracture model [14, 15]. Other authors have recommended a nonparallel screw configuration, where two of the three screws are placed in typical orientation, but the third screw is modified to be placed more horizontally into the head or neck, more perpendicular to the vertical fracture line. This may allow a true lag effect compressing the major fragments across the vertical fracture to gain stability and possibly control shearing better than an all parallel screw construct. While never proven in a comparative clinical series, applying screws in the latter, nonparallel configuration has performed significantly better in several mechanical testing studies using a vertical neck fracture model [14, 15].

The sliding hip screw (SHS) has a reasonably successful record for typical hip fractures. It is a fixed-angled device so that it may provide increased resistance to varus collapse compared to parallel screws while also allowing compression along the axis of the femoral neck. For most femoral neck fractures, this is approximately parallel to the femoral neck axis. Unfortunately, in the vertical pattern, the SHS can also induce shearing forces with axial compression, but this may be better tolerated than with cannulated screws as the device includes a fixed angle design. As such, the SHS used alone may facilitate shortening, and it also lacks rotational control. This implant showed improved mechanical testing strength similar to the nonparallel screw construct previously described and better than three parallel screws in a vertical fracture model. Some clinicians have added a long parallel screw superior to the SHS lag screw for anti-rotation and intramedullary buttress effect (Fig. 17.2b), which

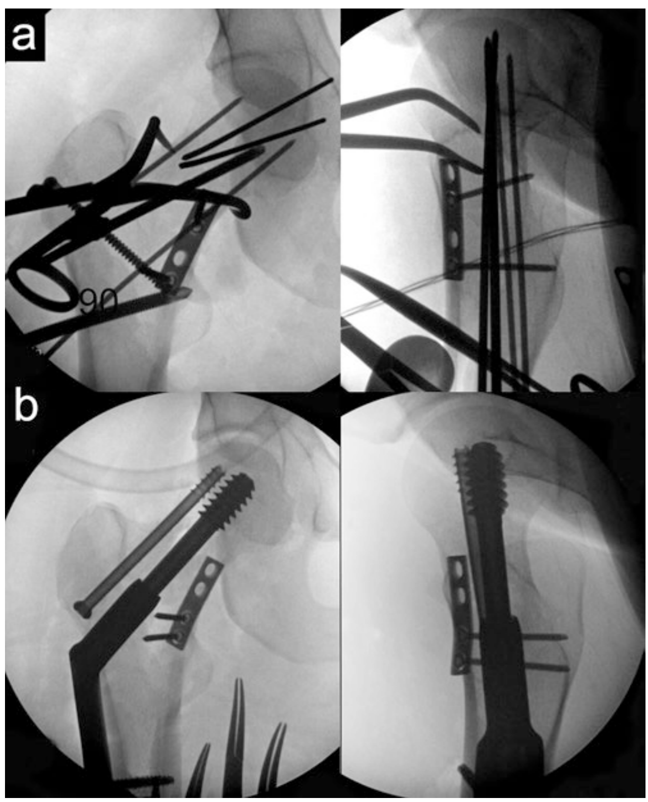

Fig. 17.2 (**a**) The reduced femoral neck fracture is provisionally held with a pointed clamp, provisional K-wires, and a medial buttress plate. (**b**) Final fixation includes a sliding hip screw, cannulated 6.5 mm anti-rotation screws, and anteromedial buttress plate

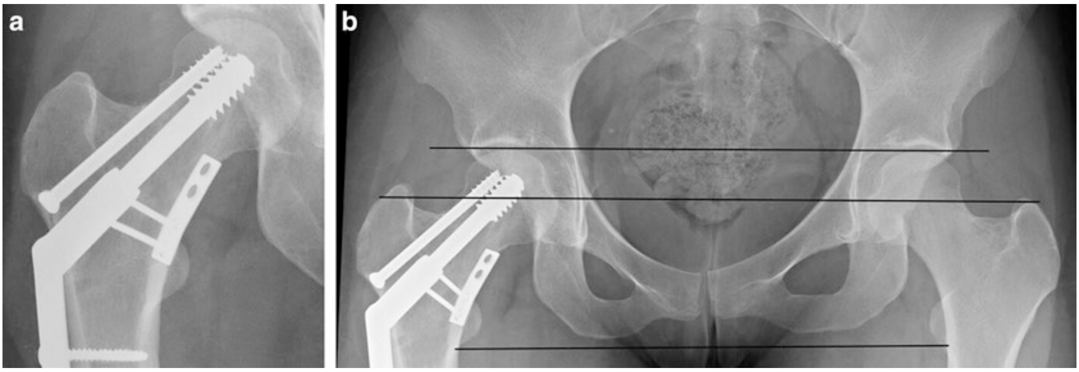

Fig. 17.3 (**a**, **b**) Final radiographs show healed fracture and minimal femoral neck shortening

seems to have improved failure rates but have still failed with varus collapse in 10% of cases.

Orthopedic surgeons frequently apply the concept of buttress (or "antiglide) plate fixation to other fractures that require resistance to shear forces. The Smith-Petersen anterior approach provides excellent visualization of the femoral neck fracture as it is anatomically reduced along the anteroinferior aspect of the femoral neck [13, 19]. A short third tubular plate, 2.7 mm Recon on DC plate (Figs. 17.2a, b and 17.3a, b), or "spider washer" is placed over the apex of the fracture spike with a bicortical screw just inferior to the spike's tip [19]. Fracture compression can still be accomplished using laterally based implants, but the ability to resist shear forces across vertical fracture is enhanced by the interdigitation of the fractures interstices and by the buttress effect of the plate. Kunapuli and coworkers [20] evaluated the use of a medial 2.7 mm buttress plate in a vertical femoral neck model repaired with three parallel screws or a SHS. They found that failure loads were increased by an average of 83%, energy absorbed to failure by 183%, and stiffness by 35%.

Evidentiary Table and Selection of Treatment Method

The studies that influence the treatment of MW are noted in Table 17.1 [5, 10, 11, 17, 21]. Based on the literature, the recommended treatment in this case of a vertical femoral neck fracture in a young patient is early surgical fixation, with medical co-management under general or spinal anesthesia.

Definitive Treatment Plan

The operative goal in treatment of femoral neck fractures in the young adult is to obtain and maintain anatomic alignment with stable fixation. These fractures are typically operated on as soon as the patient is stable (in the polytrauma patient), and the "A-team" is available to assist in the operating room. Surgery for this problem and in this patient is not an emergency but does have some urgency. Numerous biomechanical and clinical papers have shown that a fixed-angle device such as a sliding hip screw with or without an anti-rotation screw is "better" than three parallel cannulated screws. For example, Aminian and coworkers' biomechanical study found that the strongest construct for stabilizing vertical shear femoral neck fractures is the proximal femoral locking plate followed in descending order by the dynamic condylar screw, the dynamic hip screw, and the three cannulated screw configuration [15]. Recent reports indicate that this construct may be supplemented with a small medial antiglide plate to gain even more mechanical stability and perhaps prevent shortening. The FAITH study looking at 1108 patients with a femoral neck fracture was randomly assigned treatment with a sliding hip screw (n = 557) or cancellous screws (n = 551).

Table 17.1 Evidentiary table: A summary of the level of evidence for repair of the young adults' vertical femoral neck fractures

Author (year)	Description	Summary of results	Level of evidence
Papakostidis et al. (2015) [21]	Systematic review	7 eligible reports comparing the timing of femoral neck fixation in younger adults were reviewed. This study failed to prove any association between timing of femoral neck fracture internal fixation and incidence of AVN. However, it indicated that delay of internal fixation of more than 24 h would increase the risk of nonunion	I
Protzman et al. (1976) [5]	Retrospective study	22 young adults with femoral neck fractures (1) were between 20 and 40 years old, (2) had clinical and follow-up roentgenograms at least 12 months after the injury, (3) incurred fracture of the neck of the femur through normal bone, and (4) did not incur a stress fracture. The incidence of nonunion was 59%. Avascular necrosis was seen in 86%	III
Liporace et al. (2008) [11]	Retrospective study	76 Pauwels' type III femoral neck fractures treated with ORIF. 14 patients lost to follow up. Fifty-nine (95%) of fractures had good to excellent reduction, and three had a fair reduction. Despite timely, excellent reduction and accurate implant placement in the vast majority of cases, the nonunion rate was 19% for fractures treated with cannulated screws alone and 8% for those treated with a fixed-angle device	III
Haidukewych et al. (2004) [10]	Retrospective study	83 femoral neck fractures treated with ORIF. 73 fractures followed until union. Fifty-three (73%) healed after one operation with no associated osteonecrosis. Osteonecrosis is seen in 23%. The 10-year survival rate of the native femoral head free of conversion to total hip arthroplasty was 85%	III
Slobogean et al. (2015) [17]	Meta-analysis	Meta-analysis of patients 60 years old or younger to assess complication risks after a femoral neck fracture. Reviewed 41 studies with 1558 patients and found osteonecrosis in 14.7% and nonunion in 10%, of patients with displaced fractures. Reoperation was necessary in 18%	I

What they found was that reoperation rates did not differ between those included in the primary analysis: 107 (20%) of 542 patients in the sliding hip screw group versus 117 (22%) of 537 patients in the cancellous screws group (hazard ratio [HR] 0.83, 95% CI 0.63–1.09; $p = 0.18$). Subgroup analysis did indicate that displaced fractures fair better with a SHS [22]. Although there are several articles describing the treatment of femoral neck fractures in the young population, the optimal treatment for these fractures is unknown and somewhat controversial. In response, the International Hip Fracture Research Collaborative was officially established following funding from the Canadian Institute of Health Research International Opportunity Program in 2005. Currently, most experts believe that femoral neck fractures in young adults should be anatomically reduced, which in the majority of cases means using open reduction, e.g., a Smith-Petersen or Watson-Jones approach. The patient is placed supine on a radiolucent "flat-top" table with the injured leg draped free. In this way, traction is easily applied, and the extremity can be rotated or translated with great flexibility. From this anterior direction, the fracture can usually be cleaned, reduced, and held with clamps. Other tools, such as joysticks, percutaneous pins, and the medial plate, are also useful.

Fluoroscopic imaging is used in the anteroposterior (AP) view to ensure proper alignment of the femoral neck-shaft angle. The preoperative AP pelvis radiograph can be used for guidance to obtain proper alignment by comparison with the contralateral hip for neck-shaft alignment and evaluation of the relationship between the tip of the greater trochanter and the center of the femoral head. On the lateral fluoroscopic view, the femoral neck alignment should be carefully assessed and the head-neck-shaft alignment assessed with the goal of restoring the patient's version (compared to the contralateral side), with care to assure that no posterior sag of the fracture or malrotation exists.

After the patient is prepped and draped in a normal sterile fashion, a 10–12 cm incision is made 3 cm distal to the anterior inferior iliac spine, with sharp dissection lateral to the sartorius and medial to the tensor fascia lata. The deep interval is between the rectus and gluteus medius, and exposure may be increased by taking down the tendon of the rectus origin with a 1 cm stump. It should be tagged and repaired on the way out. This should expose the thick anterior capsule of the hip. One can palpate the anterior rim of the acetabulum and radiographically confirm a longitudinal capsulotomy incision along the anterior femoral neck. This should be "T-ed" along the labrum with enough capsular material along the acetabular rim to repair after fixation. Retractors should be carefully placed so as not to further injure the posterior blood supply along the femoral neck.

At this point, a lateral approach to the proximal femur for application of a sliding hip screw is performed. Large threaded tipped pins can be preloaded into the shaft-neck segment so that once neck quality reduction is achieved, two or three large "guide" pins can be placed across the fracture for provisional fixation. Once alignment is confirmed, they can even be passed across the acetabulum to stabilize the fracture fragments while the tap and lag screw are placed (lots of torqueing force!). Anatomic fracture alignment should be obtained prior to sliding hip screw insertion and should be reassessed frequently. If the guide pins were well placed before provisional fixation, one cranial to the sliding hip screw can be used for a 6.5 or 7.3 mm cannulated screw (or two). A cannulated reamer is used for creation of the sliding hip screw's lag screw path, and in these patients with good bone quality, a tap should be used. Assess the fracture during and after tapping as the reduction must be maintained. The lag screw is placed with careful attention to obtaining a tip-apex distance (TAD) of less than 20 mm on combined AP and lateral views. A two-hole side plate is plenty long for side plate fixation in these cases, unless an associated shaft fracture is present and there is the need to overlap implants. A small medial buttress plate (e.g., 3-hole one-third tubular or short 2.7 mm plate) can be applied before or after other implants as desired – sometimes it can aid in reduction. Clamps on the femoral neck should be kept in place until *all* fixation is applied.

The wounds are closed in a standard layered fashion. The patient is permitted full weight-bearing with two-arm support. Geriatric patients are medically co-managed during the perioperative period, with careful attention to their comorbidities, deep venous thrombosis prophylaxis with mechanical and chemical agents, and avoidance of delirium. Adequate follow-up is ensured for evaluation and treatment of osteoporosis and prevention of future fragility fractures.

Predicting Long-Term Outcomes

Complications, some of which are devastating, are common after femoral neck fractures in the young adult population. Slobogean and coworkers [17] recently performed a meta-analysis of patients 60 years old or younger to assess complication risks after a femoral neck fracture. They reviewed 41 studies with 1558 patients and found osteonecrosis in 14.7% and nonunion in 10%, of patients with displaced fractures, and reoperation was necessary in 18% of these patients.

Malunion occurs in the vast majority of these cases if careful measurements and reasonably strict definitions are applied. Zlowodzki and colleagues [23] found moderate (5–10 mm) to severe (>10 mm) shortening in 66% and >5° varus in 39% of 70 patients with a femoral neck fracture in a multicenter cohort study. Patients with either moderate or severe shortening of the femoral neck had dramatically poorer short form-36 questionnaire (SF-36) and EuroQol function scores versus those with no or mild shortening (<5 mm). Varus collapse also correlated with the occurrence of shortening. Stockton and colleagues [24] reported shortening of >5 mm in 54% of patients <60 years old treated with repair for a femoral neck fracture, including 32% of patients that shortened >10 mm. Ninety-three percent of patients had Pauwels' II or III fractures. Initially displaced fractures shortened more than non-displaced fractures. Interestingly, patients treated with a SHS and anti-rotation screw shortened 2.2 mm more than those treated with screws alone, although the authors assert that this finding was likely the result of selection bias (use of SHS in more difficult fractures). Treatment of symptomatic femoral neck malunion may include observation, a shoe lift, corrective osteotomy, or arthroplasty depending on the patient's symptoms, physiology, and age [24].

Nonunion appears closely tied to a loss of mechanical stability in young adult patients with a femoral neck fracture. Initial fracture displacement, quality of reduction, fixation construct, and increasing patient age have correlated with an increased risk of nonunion [11, 25]. It is accepted that mechanical factors (as opposed to biologic) are more central to the occurrence of nonunion in vertical young patient fractures compared to typical femoral neck fractures in older patients. Nonunion rates for displaced femoral neck fractures in young adults are typically reported at 10–33% [11, 25]. Although beyond the scope of this chapter, treatment of femoral neck nonunion may include a valgus intertrochanteric osteotomy or arthroplasty depending on the viability of the femoral head and the physiology and age of the patient.

Osteonecrosis of the hip is found in 2–24% of patients treated in modern series. Slobogean and colleagues [17] reported an incidence of osteonecrosis for isolated fractures at 14.3%. Fracture displacement was the only contributing factor identified for osteonecrosis (14.7% vs. 6.4%). Direct arterial injury and/or local pressure increases (like compartment syndrome) may be contributory. The timing of surgical treatment is discussed previously in this chapter. Treatment of femoral head osteonecrosis may include observation, medication, osteotomy, a vascularized fibular strut, or arthroplasty depending on the stage of AVN and the physiology and age of the patient.

Another treatment option is hemiarthroplasty and total arthroplasty. All treatment methods have potential drawbacks. With ORIF, if fixation fails or if nonunion occurs, reoperation is often necessary. With arthroplasty the potential drawback is the requirement of revision surgery within the patient's lifetime. A recent analysis by Swart and colleagues, looking at treatment with ORIF, hemiarthroplasty, and total arthroplasty through a Markov decision analytic model, found that THA was a cost-effective option for a displaced femoral neck fracture in an otherwise healthy patient who is >54 years old, a patient with mild comorbidity who is >47 years old, and a patient with multiple comorbidities who is >44 years old. The average clinical outcomes of THA and ORIF were similar for patients 40–65 years old, although ORIF had a wider variability in outcomes based on the success or failure of the initial fixation. For all ages and cases, hemiarthroplasty was associated with worse outcomes and higher costs, while a relatively young patient who undergoes arthroplasty may need revision within his or her lifetime [26].

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Part V

Lower Extremity Trauma

18 Diaphyseal Femur Fractures

Paul S. Whiting, Obioma V. Amajoyi, and Manish K. Sethi

JM: 32-Year-Old Male with a Femoral Shaft Fracture

Case Presentation

JM is a 32-year-old male (BMI 25) who presents after a high-speed motorcycle collision. The patient presents to the local emergency room via EMS complaining of left thigh pain and denies any loss of consciousness. On primary survey, he has no immediately life-threatening injuries. Secondary survey demonstrates a deformed left lower extremity.

Past medical and surgical histories are unremarkable. The patient has no allergies, takes no medications, and has no significant family history. Review of systems is otherwise negative.

On physical exam, his left thigh is swollen, but the thigh compartments are soft and compressible. The skin is intact. He actively dorsiflexes and plantarflexes both ankles, and active toe flexion and extension is symmetric bilaterally. He has 2+ dorsalis pedis and posterior tibial pulses in his left foot, and his left foot is warm and well perfused. An external traction device has been placed on his left leg.

AP and lateral radiographs demonstrate a displaced mid-shaft transverse fracture of the left femur with some comminution (Fig. 18.1a, b, c).

Interpretation of Clinical Presentation

The patient's evaluation is consistent with an isolated left femoral shaft fracture. Due to the high-energy mechanisms of injury typically required to cause femur fractures, the treating orthopedic surgeon should routinely request a comprehensive trauma evaluation of the patient's head, chest, abdomen, pelvis, and spine by the emergency department or trauma service to confirm the absence of any occult injuries. In a retrospective review of 786 cases of high-energy blunt trauma over a 3-year period, Housian and colleagues demonstrated an 8.1% incidence of missed injuries [1].

It is also critical for the orthopedic surgeon to carefully assess the patient for other orthopedic injuries commonly associated with femoral shaft fractures, including acetabular fractures, femoral neck fractures, and ligamentous injuries of the knee. Acetabular fractures can usually be identified

P. S. Whiting (✉) · O. V. Amajoyi
Department of Orthopedics and Rehabilitation, University of Wisconsin-Madison, University of Wisconsin Hospital and Clinics, Madison, WI, USA
e-mail: whiting@ortho.wisc.edu

M. K. Sethi
Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA

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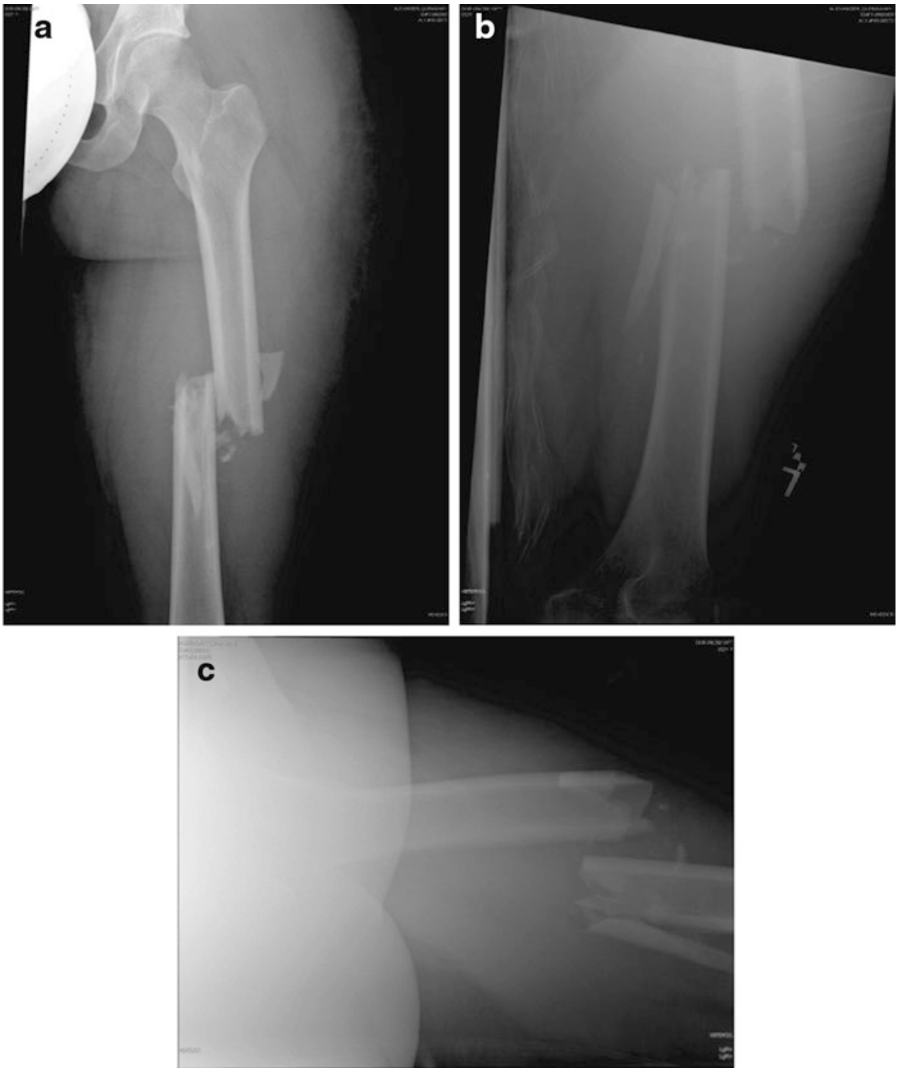

Fig. 18.1 AP (**a**) and lateral (**b**, **c**) radiographs of the left femur

on the AP pelvis radiograph, which is typically obtained in the trauma bay. However, ipsilateral knee ligamentous injuries often remain undetected. In a retrospective review of 52 patients with femoral shaft fractures at two years post-injury, Walker and Kennedy demonstrated a 48% incidence of knee ligamentous injuries, half of which were ACL tears [2]. Mean time from femoral fracture to documentation of knee instability was greater than one year. In a larger retrospective cohort of 110 patients with femoral shaft fractures, Szalay and colleagues reported a 27% incidence of ligamentous knee injury [3]. The incidence was even higher (53%) in a subgroup of 33 patients with ipsilateral femoral and tibial shaft fractures. While ligamentous injuries of the knee were diagnosed by physical exam in the studies mentioned above, a more recent case series published by Dickson and colleagues using magnetic resonance imaging (MRI) confirmed high rates of ligamentous knee injury in association with femoral shaft fractures [4]. Overall, MRI identified intra-articular pathology in 19 of 27 knees (70%), with distal femoral articular contusion being the most common (63%). Other commonly injured structures included the MCL (41%), LCL (30%), lateral meniscus (26%), and ACL (19%). Since the stability of the knee is difficult to assess in the setting of a fractured femur, ligamentous examination of the knee is best performed in the operating room immediately following femoral stabilization while the patient is still anesthetized.

Fractures of the femoral neck are critical to identify in patients with femoral shaft fractures. Failure to diagnose these associated injuries can have devastating consequences, such as femoral neck nonunion, malunion, and femoral head osteonecrosis. Associated femoral neck fractures, which are present in 2–6% femoral shaft fractures, are missed 19–31% of the time [5]. In a retrospective review of 2897 patients with femoral shaft fractures, 24 of the 91 associated femoral neck fractures (26%) were not diagnosed preoperatively [6]. 16 of these 24 patients had a negative CT scan of the ipsilateral hip preoperatively as part of the comprehensive trauma evaluation, though not all of these were fine-cut CT scans. In a similar patient population, Tornetta and colleagues reported a dramatic reduction in missed femoral neck fractures through the implementation of a standardized protocol of radiographic studies before, during, and after surgical fixation [7]. The protocol included 1) a dedicated preoperative AP radiograph of the hip in internal rotation; 2) a preoperative fine-cut (2 mm) CT scan through the femoral neck; 3) an intraoperative fluoroscopic lateral hip radiograph, and 4) postoperative AP and lateral radiographs of the hip in the operating room. This protocol decreased the authors' delay in diagnosing associated femoral neck fractures by 91%.

On initial evaluation, it is also noted that JM's left lower extremity has been placed in an external traction device. While evidence is lacking to support the use of an external traction apparatus for femoral shaft fractures, such devices are often applied in the field before the patient's arrival at a local emergency department. External traction devices are designed to improve patient comfort by decreasing mobility of the fracture. However, JM should not remain in this apparatus for a prolonged period of time, as complications including pressure ulcers and sciatic nerve injury have been reported with its use [8, 9]. Once in the hospital, a distal femoral or proximal tibial traction pin is often placed prior to definitive stabilization of the patient's femoral shaft fracture. While a systematic review failed to demonstrate a clear clinical benefit of skeletal traction in proximal femur fractures [10], there is a lack of high-quality data concerning its use in fractures of the femoral shaft. A retrospective study comparing methods of provisional fixation found no differences in perioperative hemoglobin values, transfusion requirements, or hospital length of stay when comparing skeletal traction to either cutaneous traction or splinting [11]. However, in a more recent prospective study comparing distal femoral traction to long-leg splinting for provisional immobilization of femoral shaft fractures, skeletal traction resulted in less pain during and immediately after application and did not result in any appreciable knee dysfunction at six months [12]. There were no cases of infection, neurovascular injury, or iatrogenic fracture associated with traction pin placement. In a prospective randomized trial by Even and colleagues, 65 patients with 66 femoral shaft fractures were assigned to receive either cutaneous or skeletal traction prior to definitive intramedullary nailing of a femoral shaft fracture [13]. The time required for application was significantly lower in the cutaneous traction group, and there were no differences between groups in visual analog scale (VAS) pain scores, pain medication consumption, or time to reduction in the operating room.

Declaration of Specific Diagnosis

JM is a 32-year-old male who presents with a high-energy injury that consists of a displaced, mid-shaft fracture of the left femur with some comminution.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Stabilization of the femur fracture
2. Restoration of length, alignment, and rotation
3. Mobilization of the patient to allow hip and knee range of motion
4. Maintenance of muscle strength
5. Return to normal life activities

Treatment options include:
Conservative/nonoperative treatment:

1. Casting/skeletal traction

Surgical treatment:

1. Plate fixation
2. External fixation
3. Intramedullary nail fixation (reamed vs. unreamed)
   (a) Antegrade with piriformis entry
   (b) Antegrade with trochanteric entry
   (c) Retrograde

Evaluation of the Literature

In order to identify relevant publications on diaphyseal femur fractures, Medline and PubMed searches were performed. Keywords included the following: "femur fracture" and "diaphyseal." Subheadings included "conservative treatment" and "surgical treatment." This search identified more than 1900 abstracts that were reviewed. From this search, more than 200 articles were read, and reference lists were reviewed. The search was limited from 1985 to 2017.

Detailed Review of Pertinent Articles

As mentioned previously there are multiple treatment options for this patient with a mid-shaft fracture of the femur. The following discussion explores the relevant literature in order to determine the most optimal treatment for patient JM.

Conservative/Nonoperative Treatment

In the past, definitive treatment of diaphyseal femur fractures with a cast or brace has been attempted, particularly in the developing world where resources are limited. In a prospective review of 106 patients with femoral shaft fractures, Hardy demonstrated suboptimal results with cast treatment including a 27% incidence of skin ulcers from casting [14]. Furthermore, maintenance of proper length, alignment, and rotation was quite difficult with cast treatment, as evidenced by a 20% incidence of femoral malrotation and a 12% rate of shortening greater than 2 cm.

Buxton reported the results of definitive femoral shaft treatment using Perkins skeletal traction in a series of 50 patients. While this method boasted an acceptable union rate of 94% at 12 weeks, 36% of patients developed pin-tract infections, and 8% went on to refracture through their initial site of injury [15].

While treatment goal 1 can be achieved through conservative treatment, the evidence suggests that goals 2–4 are much more difficult to attain. Since patient JM is a young male who is likely to remain active in the future, and considering the unfavorable results expected with conservative treatment of diaphyseal femur fractures, the authors recommend surgical intervention for JM's fracture.

Surgical Treatment

Plate Fixation

Femoral shaft fractures may be treated surgically with extramedullary plate fixation. Indications for plating of femoral shaft fractures include severe pulmonary dysfunction, certain ipsilateral femoral neck and shaft fractures, associated vascular injuries, previous deformities, and periprosthetic fractures [16]. In the developing world, however, where specialized fracture tables and intraoperative fluoroscopy are not always available, plate fixation is utilized more commonly. In a retrospective review of 500 femoral shaft fractures that underwent plate osteosynthesis, Smrke and Princic argued that plating was an effective technique for isolated femoral shaft fractures with a reported union rate of 85% [17]. However, several smaller retrospective studies have reported higher complication rates associated with plate fixation. Seligson and colleagues [18] reported a 30% incidence of complications with fracture healing in a series of 15 patients treated with plate osteosynthesis, which was significantly greater than the complication rate in a matched cohort of patients who underwent intramedullary nailing (12%). In another series of 199 fractures treated with plate fixation, the overall complication rate was 23%, including a 2.5% rate of deep infection [19]. Reported rates of infection following open femoral plating range from 2% to 10% [19].

While open reduction and internal fixation would stabilize this patient's injury, more reliably maintain acceptable reduction, and permit early mobilization and joint range of motion, it would not allow him to bear weight immediately. Delayed weight-bearing coupled with high reported complication rates makes plate osteosynthesis a less than optimal treatment for patient JM.

External Fixation

On presentation to the emergency department, JM appears to be hemodynamically stable with a closed injury. However, if his clinical picture were to deteriorate, external fixation would be an attractive option for provisional stabilization with later conversion to definitive fixation. Nowotarski and colleagues retrospectively reviewed 1507 patients who were converted from external fixation to a statically locked intramedullary nail, with an average time to conversion of 1 week [20]. At 1 year follow-up, the authors reported a 97% rate of union with only a 1.7% infection rate. In a retrospective case series of 125 femoral shaft fractures in military personnel that underwent temporary external fixation in an austere environment prior to definitive IM nailing, the infection rate was 2.5% with an average follow-up of 41.4 months [21]. This study further supports the safety of provisional external fixation prior to conversion to intramedullary nailing, even if the external fixator is applied in an austere setting. Scannel and colleagues, in a recent retrospective study of 205 patients treated with skeletal traction or external fixation prior to definitive treatment with intramedullary nailing, demonstrated no major difference in clinical outcomes with an average delay of 4–5 days [22]. As such, the treating surgeon could also consider initial stabilization of JM's femur fracture using skeletal traction for up to 5 days prior to definitive fixation with an intramedullary nail. While several studies report the use of external fixation as a means of definitive treatment for adult diaphyseal femur fractures, high rates of malunion and pin-tract infection make external fixation a less desirable option for definitive bony stabilization in our patient JM [23].

Intramedullary Nail Fixation

Antegrade Intramedullary Fixation

Intramedullary (IM) nailing has several advantages compared with other methods of stabilization for fractures of the femoral shaft. Over the past three decades, IM nailing has become the standard of care for most diaphyseal femur fractures – not only in developed countries but also in the developing world [24]. Intramedullary nailing is extremely effective and has a high rate of success in achieving union; restoring proper length, alignment, and rotation; and allowing early mobilization and weight bearing. In a large retrospective review of 551 diaphyseal femur fractures treated with an antegrade, statically locked, reamed nail placed via a piriformis entry point, Wolinsky et al. reported a union rate of 98.9% and an infection rate of less than 1% [25]. All six fractures that became infected healed after adequate treatment and were infection-free at final follow-up. There was only one case (0.2%) of nail breakage, and this occurred at 17 months in the setting of a fracture with bone loss. Thirteen locking bolts broke without influence on either treatment or outcome. All fractures healed with less than 10° of angulation in any plane. In this series, the use of a fracture table did not influence clinical outcomes. However, the same authors previously reported that fracture table use is associated with an average increase in operating time of 60 min compared to fracture fixation on a standard radiolucent table [26].

Other advantages of locked intramedullary nailing include immediate joint mobilization, early muscle rehabilitation, decreased hospital length of stay, and early return to work [27]. Furthermore, IM nailing offers the advantage of immediate weight bearing. In a retrospective study of 24 patients with diaphyseal femur fractures treated with an antegrade statically locked reamed nail, early full weight bearing did not inhibit union [28]. Biomechanical and clinical data also support the safety of immediate weight bearing after fixation of comminuted femoral shaft fractures with a statically locked intramedullary nail, even in the setting of significant comminution [28, 29].

Positioning

In positioning for an antegrade nail, the patient may be placed in either the supine or lateral position. In a retrospective comparative study of 988 patients with femoral shaft fractures treated with antegrade femoral nails, Apostle et al. demonstrated no difference in long-term outcomes based on positioning in either the supine or lateral position [30]. Two other retrospective case series of lateral positioning for antegrade intramedullary nailing have reported a 100% rate of union with rates of malreduction that compare favorably to antegrade nailing in the supine position [31, 32].

Reduction

Regardless of patient positioning, the surgeon must decide whether to accomplish fracture reduction via closed or open techniques. Opening a closed fracture for the purposes of reduction has been shown to be an independent risk factor for nonunion [33]. A small retrospective series comparing open vs. closed nailing reported a slightly longer time to union with open nailing (median 5 months vs. 4 months with closed nailing) [34]. In the 17 patients that underwent open nailing, there was one case of nonunion and one case of fixation failure (6% incidence for each complication). None of the 18 patients who underwent closed nailing experienced nonunion or fixation failure, and there were no cases of superficial or deep infection in either group. Whenever possible, closed reduction followed by reamed intramedullary nailing should be accomplished. However, eccentric reaming caused by an imperfect reduction can lead to malreduction after nail placement. As such, in order to achieve excellent alignment following nailing, maintenance of fracture reduction during reaming is critical. Alternatively, the technique of "push past" reaming, in which reaming is performed proximal and distal to (but not at) the fracture site, has been shown to be effective in achieving excellent postoperative reduction [35].

Starting Point

Selection of a starting point for antegrade femoral nailing is a controversial topic in the literature. The two standard starting points for antegrade nailing are the 1) piriformis fossa (piriformis entry) and 2) tip of the greater trochanter (trochanteric entry). A cadaveric study demonstrated an increased incidence of injury to the hip abductors, hip external rotators, and the deep branch of the medial femoral circumflex artery with the piriformis portal compared to the trochanteric portal [36]. A similar cadaveric study describing a modified medial trochanteric portal found no visible damage to the gluteus medius tendon or its insertion when this portal was accurately achieved [37]. A more recent cadaveric study by Schottel et al. demonstrated no statistically significant difference in femoral head perfusion between piriformis entry and trochanteric entry portals [38].

A retrospective comparative trial investigating functional outcomes found that piriformis entry nailing was associated with greater incidence of a Trendelenburg gait compared with trochanteric entry nailing [39]. Isokinetic analysis determined that the piriformis entry portal caused acute injury to the superior gluteal nerve with subsequent reinnervation, resulting in a significant decrease in both hip abductor and external rotator strength. In a similar study using isokinetic muscle testing, Helmy et al. demonstrated a statistically significant decrease in hip abduction and extension strength following piriformis entry nailing [40]. However, at 1-year follow-up, there was no significant disability as measured by Short Musculoskeletal Assessment (S-MSA) and Short Form (SF)-36. Ricci et al. compared trochanteric entry and piriformis entry antegrade nailing in a prospective cohort study of 104 patients and reported no difference in union rates, complication rates, or functional outcomes between the two groups [41]. More recently, Stannard et al. conducted a prospective randomized controlled trial (RCT) of 110 patients comparing the two entry portals and found equivalent functional outcomes between groups [42]. The authors did, however, demonstrate a significantly shorter operative time with the use of the trochanteric entry portal in obese patients. Gait analysis data have also shown no differences in trochanteric versus piriformis starting points for intramedullary nail fixation of femur fractures [43]. Using a piriformis or trochanteric starting portal for an antegrade locked intramedullary nail is acceptable and standard practice.

Reaming

Controversy has also existed surrounding the decision to perform intramedullary reaming prior to placement of a femoral nail. Shepherd et al. conducted a prospective RCT of 100 patients with diaphyseal femur fractures and demonstrated faster operative times with the unreamed technique with no difference in perioperative complications between the reamed and unreamed groups [44]. However, a prospective study of 122 patients with diaphyseal femur fractures treated with unreamed nailing reported a nonunion rate of 5.1% [45]. The increased risk of nonunion with unreamed nailing was confirmed in a prospective RCT of 172 patients published by Tornetta and Tiburzi [46]. The authors identified a significant increase in time to union with unreamed nailing (158 days vs. 80 days with reamed nailing), with no significant difference in operative time between groups. Six years later, a multicenter RCT conducted by the Canadian Orthopedic Trauma Society compared rates of pulmonary complications in 322 multiple trauma patients who underwent either reamed or unreamed nailing, and found no significant difference in the incidence of acute respiratory distress syndrome (ARDS) between groups [47]. In a large retrospective comparative study of 443 polytrauma patients with femur fractures treated with either plate or intramedullary nail fixation, Bosse and colleagues reported no difference in pulmonary complications between groups [48]. Two separate meta-analyses comparing reamed vs. unreamed femoral nailing have demonstrated that reamed nailing is associated with significantly decreased rates of reoperation, nonunion, and delayed union, with no difference in the incidence of ARDS, mortality, or hardware failure between groups [49, 50]. The former study identified a statistically significant decrease in operative blood loss with unreamed nailing, but this difference was not significant in the more recent meta-analysis, which included more patients.

Rotation

Obtaining proper rotational alignment while performing intramedullary nailing of femoral shaft fractures is a significant challenge, and rotational malreduction is common. A retrospective review of 82 femoral shaft fractures treated with intramedullary nail fixation used a postoperative CT scan to determine the degree of femoral malrotation present after nailing [51]. The authors identified malrotation greater than 15° in 18/82 patients (22%). The degree of malrotation was associated with the fracture severity, with OTA type C fractures having a significantly higher average degree of malrotation (19.4°) vs. type B or type A fractures (9° and 6.6°, respectively). The average degree of malrotation was also higher in cases performed at night compared with those performed during the day (15.2° vs. 10.8°). There was no difference in the incidence of malrotation in closed vs. open fractures, retrograde vs. antegrade nailing, or level of experience of the surgeon. Regardless of the technique by which intramedullary nailing is performed for a femur fracture, one must take precautions to avoid malrotation of the femur in JM. While there are no evidence-based techniques, various technical tricks have been proposed [52].

Timing of Intramedullary Nailing

From the available evidence, reamed IM nailing of femur fractures appears to be safe and results in acceptably low rates of pulmonary complications, even in multiply-injured patients. Nonetheless, for patients with a known pulmonary contusion or those whose physiologic status is unstable or in extremis, pursuing a damage control orthopedic strategy involving external fixation of the femur fracture may be more prudent, as the adverse physiologic effects of reaming on pulmonary function may be more detrimental in such patients [53]. Adherence to established protocols for resuscitation prior to proceeding with definitive nailing has been shown to decrease perioperative complications [53–55] and decrease hospital length of stay and costs [56]. For a more detailed review of polytrauma management and decision-making, see Chap. 29.

At least two studies have investigated the impact of time of day on outcomes following femoral nailing. A large retrospective study investigating 340 fractures fixed during the daytime (defined as 7:00 am-6:59 pm) vs. the nighttime found no statistically significant difference in postoperative femoral version or length between groups [57]. A prospective trial comparing femoral nailing during "daytime hours" (defined as 6 am-4 pm) to "after hours" in 203 fractures reported no difference between groups in operative time, fluoroscopic time, alignment, nonunion, infection, or reoperation [58]. However, fractures fixed after hours had a significantly higher rate of reoperation due to hardware-related complications (27% vs. 3%).

Outcomes

In a retrospective study investigating long-term functional outcomes following intramedullary nailing for femoral shaft fractures, moderate to severe pain was reported by 10 of 59 patients (17%) at an average follow-up of 7.8 years. A significant correlation was observed between pain in the lower limb (as determined by VAS score) and the patient-reported outcome scores measured (Short Musculoskeletal Functional Assessment (SMFA), Western Ontario and McMaster University Osteoarthritis (WOMAC) index, Harris Hip Score (HHS), and the Lysholm knee function scoring score) [59]. There were no differences in final hip or knee range of motion compared to the contralateral uninjured extremity. The authors concluded that pain in the lower limb is an important predictor of ongoing disability after IM nailing of femoral shaft fractures, even though most patients achieve good functional outcomes and regain normal range of motion. Another study investigated the relationship between hip muscle strength and long-term functional outcomes in 48 patients following femoral intramedullary nailing [60]. Patients with lower scores on functional strength assessments (isometric muscle strength testing and the 30-s chair to stand test) were more likely to have lower functional outcomes scores (including the hip disability and osteoarthritis outcome score (HOOS) and the Eq5D-5 L).

Retrograde Intramedullary Fixation

Indications

Another option to consider in treating JM would be retrograde intramedullary nailing. For certain patient populations such as pregnant women and the obese, retrograde intramedullary nail fixation is much easier to accomplish and is the preferred method of nailing. A prospective multicenter study of 151 obese patients reported significantly decreased radiation exposure and shorter operative times with retrograde nailing compared to antegrade nailing [61]. Certain associated injuries also make retrograde nailing advantageous. In the setting of associated pelvic, acetabular, or proximal femoral fractures, retrograde nailing permits stabilization of the femoral shaft fracture without interfering with placement of incisions for eventual fixation of the associated proximal injuries. With ipsilateral femoral and tibial fractures, retrograde nailing allows both long bones to be stabilized via a single incision.

Outcomes

Several studies have investigated the clinical outcomes of retrograde nailing. A prospective RCT involving 100 patients reported no significant difference in union or complication rates between antegrade and retrograde femoral nailing [62]. In a large retrospective study of 293 patients, antegrade nailing and retrograde nailing were associated with equivalent rates of delayed union, nonunion, and malunion [63]. However, when patients with injuries to the ipsilateral knee or hip were excluded, knee pain was more common following retrograde nailing (36% vs. 9%), and hip pain was more common following antegrade nailing (10% vs. 4%). Another retrospective study of 75 patients who underwent unilateral or bilateral retrograde femoral intramedullary nail fixation identified a 23% incidence of knee pain at final follow-up [64]. Among the 17 patients with knee pain, 1 case resolved spontaneously, and the other 16 resolved following removal of distal interlocking screws (n = 12) or the nail (n = 4). To investigate this outcome further, Daglar et al. conducted a prospective RCT of 70 patients treated with antegrade vs. retrograde intramedullary nail fixation of a femoral shaft fracture [65]. The authors found no differences between groups in final knee ROM, Lysholm scores, or peak torque deficiencies as measured by isokinetic evaluation.

Halvorson and colleagues reviewed a large retrospective cohort of 185 patients to determine the risk of ipsilateral knee septic arthritis following retrograde femoral nailing [66]. In the nine patients who developed a postoperative infection, there were no cases of knee involvement suggestive of septic arthritis. In another study investigating 34 patients with femoral shaft fractures and ipsilateral traumatic knee arthrotomies, Bible et al. reported no cases of postoperative infection within the knee joint or the fracture site following retrograde femoral nailing [67]. In summary, retrograde nailing is a reliable and safe method of femoral shaft fixation, even in the setting of a traumatic arthrotomy or open fracture.

Literature Inconsistencies

The relative lack of prospective randomized controlled trials is a major challenge in reviewing the evidence pertinent to the treatment of diaphyseal femur fractures. The literature is primarily dominated by retrospective case series and non-randomized prospective comparative trials. Additional data from prospective RCTs are needed in order to better guide decision-making.

Evidentiary Table and Selection of Treatment Method

The key studies in treating JM are noted in Table 18.1 [25, 42, 44, 46, 47, 62, 65]. Based on the literature, the authors feel that the best treatment in this case would be an antegrade reamed statically locked nail placed using a trochanteric or piriformis entry portal. However, a retrograde femoral nail is certainly a reasonable option as well.

Definitive Treatment Plan

The overall goal in intramedullary nail fixation of femoral shaft fractures is to attain and maintain normal anatomic length, alignment, and rotation compared to the contralateral femur. Anatomic length, alignment, and rotation is easier to achieve in transverse fractures. However in severely comminuted fractures, it is much more challenging to obtain the correct length and rotation. Radiographs of the contralateral femur can help assess length, rotation, and angulation.

Prior to positioning, one can obtain a rotational profile of the contralateral femur. This is done with the patient in the supine position. A perfect lateral fluoroscopic image of the uninjured knee is obtained. The C-arm is then rotated 90°, and an AP image of the uninjured hip is obtained. These images are saved for later reference. The radiographic profile of the lesser trochanter on the AP view of the uninjured hip is important for assessing appropriate rotational alignment of the fractured side. If significant comminution or bone loss is present, a radiographic ruler can be used to measure the length of the contralateral uninjured femur, and this measurement can be used to restore appropriate length to the fractured side during intramedullary nailing.

Table 18.1 Evidentiary table*:* A summary of the quality of evidence for antegrade reamed nailing of femoral shaft fractures

Author (year)	Description	Summary of results	Level of evidence
Wolinsky et al. (1999) [25]	Retrospective cohort study	551 diaphyseal femur fractures treated with closed antegrade statically locked reamed nailing demonstrated a union rate of 98.9% and an infection rate of less than 1%	III
Ostrum et al. (2000) [62]	Randomized prospective control trial	100 patients with femoral shaft fractures. No significant difference in union or complication rate was demonstrated between either retrograde or antegrade nailing	I
Tornetta and Tiburzi (2000) [46]	Prospective randomized	172 patients underwent reamed versus unreamed antegrade nailing with reamed group demonstrating faster rate of union and equal operative time between groups	I
Canadian orthopedic trauma association (2006) [47]	Prospective randomized	322 patients with diaphyseal femur fractures treated with either reamed or unreamed antegrade femoral nails demonstrated no significant difference in the incidence of acute respiratory distress syndrome (ARDS)	I
Shepherd et al. (2001) [44]	Prospective randomized	100 patients with diaphyseal femur fractures treated with reamed or unreamed nailing demonstrated faster operative times with unreamed nailing technique with no difference in perioperative complications between groups	I
Daglar et al. (2009) [65]	Prospective randomized	70 patients treated with antegrade vs. retrograde IMN fixation of a femoral shaft fracture demonstrated no differences between groups in final knee ROM, Lysholm scores, or peak torque deficiencies as measured by isokinetic evaluation	I
Stannard et al. (2011) [42]	Prospective randomized	110 patients comparing trochanteric vs. piriformis starting points. Equivalent functional outcomes between groups; operative time significantly shorter with trochanteric portal in obese patients	I

The authors favor placing the patient without traction on a radiolucent table with a bump under the ipsilateral buttock to place the pelvis in approximately 20° of internal rotation. After the patient is prepped and draped in the usual sterile fashion, a 4-cm incision is made proximal to greater trochanter down to the gluteus fascia, which is then split. Digital palpation and/or heavy scissors are used to spread bluntly through the gluteus medius. A guide pin is then placed into the tip of the greater trochanter and advanced to the level of the lesser trochanter. Its trajectory is assessed using fluoroscopic evaluation.

Once the guide wire is in line with the femoral shaft in both the AP and lateral planes, the center of the femoral canal can be over-reamed with a large opening reamer. At this point, a guide wire is inserted, and closed reduction is performed. After appropriate reduction is obtained and the guide wire is placed across the fracture, the femoral canal is then reamed and the antegrade femoral nail placed. Interlocking screws are placed through the nail on one side of the fracture.

Prior to final fixation, the bump is removed from beneath the ipsilateral hip, and a rotational profile of the injured extremity is obtained with the patient in the supine position. This rotational profile is then compared to the preoperative fluoroscopy views of the uninjured femur, with close attention paid to the radiographic profile of the lesser trochanter. If alignment appears adequate, the other interlocking screws can be placed.

After completing interlocking of the intramedullary nail, the femoral neck should be examined under fluoroscopy with internal and external rotation to assure that no femoral neck fracture is present. The skin and subcutaneous tissue are closed. An AP pelvis radiograph with the hips in maximal internal rotation is then obtained to assure no femoral neck fracture.

Postoperatively the patient will be allowed full weight bearing as tolerated on both lower extremities.

Predicting Long-Term Outcomes

As mentioned previously, the vast majority of patients who undergo intramedullary nail fixation of a femoral shaft fracture regain excellent functional outcomes and normal knee and hip range of motion [68]. The most important predictor of ongoing disability after IM nailing of femoral shaft fractures is chronic knee pain.

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19 Distal Femur Fractures

William M. Ricci, A. Alex Jahangir, and Christopher D. Parks

AC: 71-Year-Old Male with Knee Pain After Fall

Case Presentation

AC is a 71-year-old male who presents to the emergency department with a chief complaint of right knee pain after falling down a flight of stairs. There are no other injuries, no loss of consciousness, and his GCS is 15. On primary survey, the exam is consistent with an injury about the right knee, the airway is patent, and he is hemodynamically stable. The secondary survey provides no additional findings.

Past medical history is negative. The patient takes no medications and has no allergies.

Physical examination demonstrates swelling, tenderness, and an effusion of the right knee. Passive and active range of motion of the knee is not possible due to pain. There is gross instability to varus and valgus stress of the right knee region. There are no open wounds. The dorsalis pedis and posterior tibialis pulses are palpable and equal to the contralateral lower extremity. Sensation to light touch is intact in all dermatomal distributions. No pain or deformity is noted in the thigh, leg, ankle, or the foot.

Radiographs of the right knee and CT scan of the knee are demonstrated in Figs. 19.1a, b and 19.2a–d.

Interpretation of the Clinical Presentation

This patient's symptoms and physical and radiographic findings are consistent with a distal femur fracture. The AP and lateral radiographs, as well as the CT scan, demonstrate a supracondylar distal femur fracture with extension of the fracture into the articular surface in the sagittal plane.

Due to the moderate energy mechanism of injury, initial evaluation should include a complete clinical evaluation to rule out injuries to the head, chest, and abdomen. After confirming that the distal femur fracture is an isolated injury, a focused physical exam further evaluates the status of the skin to assess if there is an open wound and the neurovascular status. Distal femur fractures are generally evaluated with radiographs

W. M. Ricci (✉)
Hospital for Special Surgery, Weill Cornell School of Medicine, New York, NY, USA
e-mail: ricciw@hss.edu

A. Alex Jahangir
Department of Orthopedic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA

C. D. Parks
Department of Orthopedics, New Hanover Regional Medical Center, Wilmington, NC, USA

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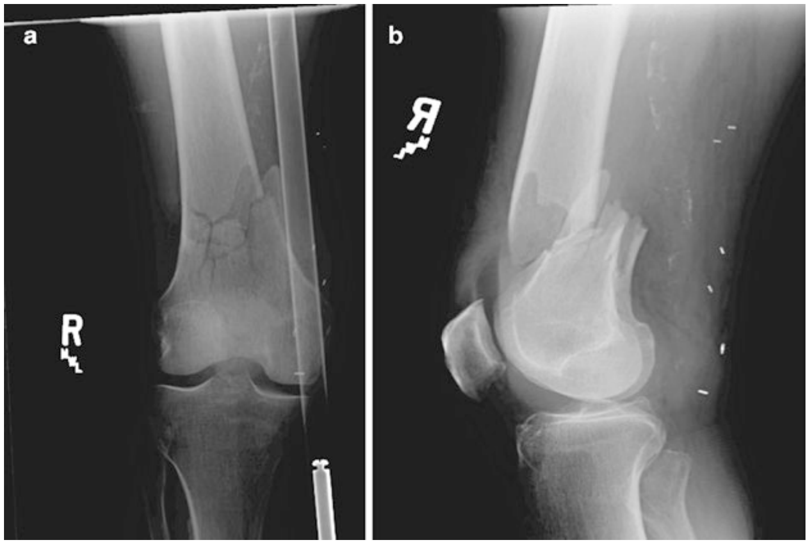

Fig. 19.1 (**a**) AP radiograph knee. (**b**) Lateral radiograph knee

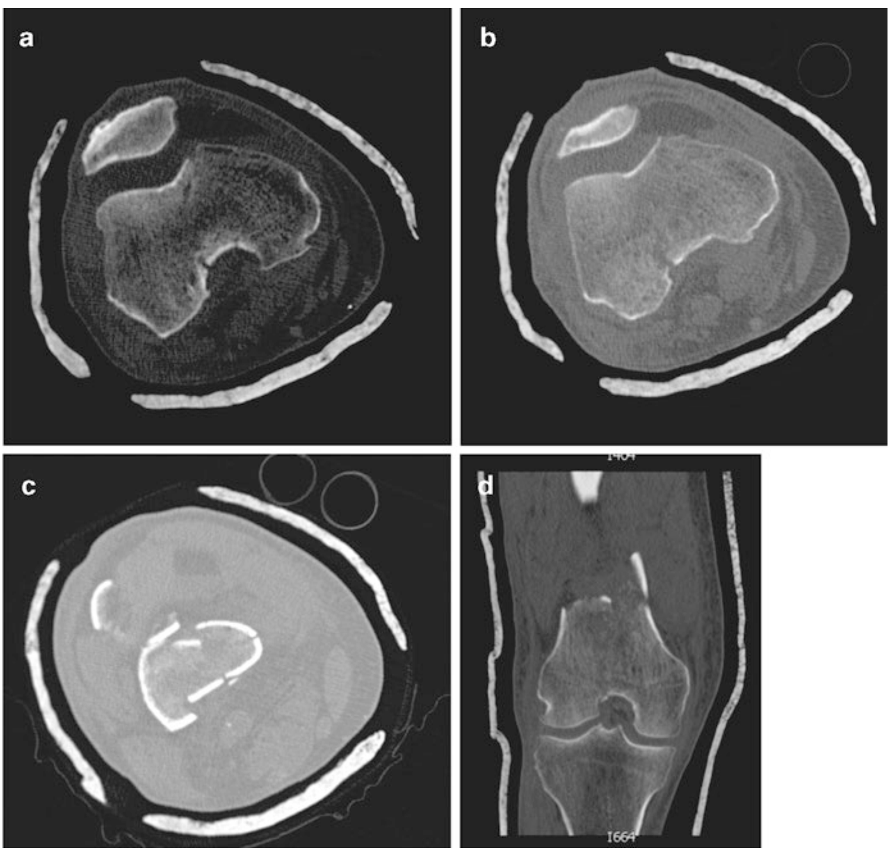

Fig. 19.2 (**a-c**) Axial CT distal femur. (**d**) Coronal CT distal femur

(AP and lateral) of the entire femur and knee. A CT scan of the knee with coronal and sagittal reconstructions is useful to rule out occult intra-articular fractures or to delineate known intra-articular fracture components. Nork and coworkers found a 38.1% incidence of a coronal plane fracture (Hoffa fracture) in distal femur fractures with intracondylar extension [1]. Furthermore, nearly 30% of coronal plane fractures were missed in this series, with plain radiographs leading the authors to recommend CT imaging for all supracondylar-intercondylar distal femur fractures in order to improve diagnostic yield and assist with preoperative planning [1, 2]. The majority of the coronal plane fragments involved a single condyle, most commonly the lateral condyle; however, Hoffa fractures of both the medial and lateral femoral condyle were identified in 8.9% of all distal femur fractures [1]. Finally, patients with an open supracondylar femur fracture were 2.8 times more likely to have a Hoffa fracture compared to those with closed fractures [1].

There are no clear evidence-based guidelines regarding the best method of provisional reduction and stabilization of the fractured distal femur. General principles of fracture reduction should be adhered to. Angular deformities in the coronal plane (varus or valgus) are usually easily correctable with manual manipulations, whereas the typical apex posterior deformity seen with this injury can be difficult or impossible to correct by closed means. A long leg splint or skeletal traction (femoral or tibial) can be used successfully. The severity of the soft tissue envelope injury, the stability of the fracture, and the patient's body habitus should all be considered. While no studies of initial management have been published, skeletal traction is not often required unless a substantial delay from injury to surgery is anticipated and the injury is prone to axial shortening.

Fractures of the distal femur are painful, and one objective during the initial assessment should be to minimize patient discomfort. In a study evaluating modalities to minimize pain in patients with acute distal femur fractures, Mutty and coworkers randomized patients with diaphyseal and distal femur fractures to receive femoral nerve blocks in the emergency department along with standard pain management and compared these patients to patients who received no nerve block and only standard pain management protocol. It was noted that the acute pain of distal femur fractures can be significantly and safely decreased through the use of a femoral nerve block administered in the emergency department [3].

Declaration of Specific Diagnosis

AC is a 71-year-old male who presents with a displaced distal femur fracture with intra-articular extension.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Reestablishment of the articular surface congruency
2. Stabilization of the articular block to the diaphysis
3. Restoration of femoral alignment
4. Early patient mobilization with immediate knee range of motion
5. Restoration of muscle strength
6. Return to normal pre-injury activities

Treatment options include:

Nonoperative treatment:

1. Splint or casting
2. Skeletal traction

Surgical:

1. Plate and screw fixation
2. External fixation
3. Intramedullary nail fixation:
   (a) Antegrade
   (b) Retrograde
4. Arthroplasty

Evaluation of the Literature

In order to identify relevant publications on distal femur fractures, a PubMed search was performed. Keywords included the following: "distal" and "femur fracture." The search was limited to clinical trials, meta-analysis, randomized clinical trials, review articles, and journal articles that were in English and involved adult human subjects. This search identified 1187 abstracts that were reviewed. From this initial review, 160 articles were read and reference lists were reviewed. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

There are multiple treatment options for this patient with a distal femur fracture. The following discussion explores the relevant literature in order to determine the optimal treatment.

Nonoperative Management

Until the late 1960s, closed treatment of distal femur fractures had been advocated as the best treatment option. This was primarily because viable implant options to stabilize the distal femur were unavailable. Neer and coworkers [4] and Stewart and coworkers [5] each reported better results with nonoperative compared to operative management in this time frame. However, results in these studies were primarily physician determined rather than patient determined, and malalignment was seen more often with nonoperative management.

As operative techniques and implants improved in the 1970s, surgeons began to advocate operative intervention for distal femur fractures. Schatzker in 1974 and Healy in 1983 each found better results with operative management including less time in the hospital, sooner return to activities, and better functional results with fewer nonunions and complications compared to patients managed nonoperatively [6, 7]. By the mid-1990s, operative treatment became the standard for most distal femur fractures. In 1996, Butt and coworkers, in a prospective randomized trial, demonstrated significantly better outcomes in the operative group compared to the nonoperative group, with the nonoperative group having increased rates of deep vein thrombosis, urinary tract infections, pressure sores, chest infections, and malunions compared to the operative group [8].

Based on the existing body of evidence, most of the aforementioned treatment objectives are difficult to obtain with nonoperative management. Furthermore, associated complications with nonoperative treatment are more common than in patients treated surgically, and, therefore, one should generally consider surgical treatment for patients with distal femur fractures.

Operative Management

Plate Fixation

Early ORIF techniques involved direct reduction of each fragment, the use of medial and lateral plates, and bone grafting. The associated bone devascularization with early open direct reduction techniques led to prolonged healing times. This, in combination with non-fixed angle implants, often led to varus collapse, especially when metaphyseal comminution was present, and additionally led many surgeons to routinely use adjuvant bone graft [9, 10]. The next step in the evolution of distal femoral plating techniques was the preservation of the blood supply by using an isolated lateral approach without medial exposure, indirect fracture reduction, and lateral fixation. Using these techniques, Ostrum and Geel demonstrated union in 29 of 30 patients without the use of bone graft [10]. Bolhofner and colleagues demonstrated union in all 73 patients treated with similar techniques with either a nonlocked condylar buttress plate or a fixed angle blade plate, also without bone graft, although two had delayed union and one patient had loss of reduction leading to malunion [11].

The introduction of locking plates, which offer theoretical benefits of multiple points of distal fixed angle fixation to avoid varus collapse and locked diaphyseal fixation to improve fixation in osteoporotic bone, has added to the treatment options for distal femur fractures. However, proven benefits relative to blade plate or DCS fixation are unknown. In a meta-analysis evaluating outcomes of 479 nonperiprosthetic distal femur fractures treated with locking plates, nonunion rates ranged from 0% to 17%, and delayed unions ranged from 3% to 15% [12]. Additionally, this study demonstrated that implant failure often occurred late, with 75% of failures occurring after 3 months and 50% occurring after 6 months [12].

The LISS plating system (Synthes, Paoli, PA) was among the first locked systems to be widely used for the treatment of distal femur fractures. It was optimized for percutaneous insertion, and the initial design called for unicortical self-drilling locking screws [13–16]. In a series of 123 distal femur fractures treated with the LISS by three surgeons, the authors noted a 93% rate of union without autogenous bone grafting, a low 3% local incidence of infection, and a 100% maintenance of distal femur reduction [14]. Newer generation locked plating systems provide the ability to use both non-locked and locked bicortical screws. The non-locking capabilities allow the surgeon to leverage the precontoured plates as a reduction aide, and the bicortical screws provide improved torsional stability. A prospective multicenter randomized controlled trial comparing LISS plates and dynamic condylar screw systems lead the authors to discontinue the use of lateral unicortical locking (LISS) in favor of other devices with locked or non-locked bicortical fixation [17].

Locked plating technology and the understanding of its biomechanics has advanced even further to include polyaxial or variable angle (VA) locking screws and dynamic or far cortical locking screws. VA locking distal femur plates have been shown to have a higher rate of early failure for type C fractures [18] and a statistically faster mean time to failure of 147 days for the VA group compared to 356 days for fixed angle LISS plating. However, in a prospective randomized multicenter clinical trial, a polyaxial locked plating system showed better knee flexion throughout follow-up and higher early callus formation leading the authors to believe polyaxial locked plates tend to result in better functional and radiological outcomes compared to LISS [19].

Dynamic locking technique is when locking screws are allowed to toggle about the near cortex while being normally fixed in the far cortex. Two studies have evaluated "dynamic" fixation of distal femur fractures, one created dynamic constructs by implant design and one by surgical technique where standard locking screws are used through an overdrilled near cortex. Each method provides additional motion between the locked head and the far cortex [20, 21]. The studies concluded that dynamic locked plating is safe and may provide a way to reduce nonunion rates seen with standard locked plating.

Based on the evidence, open reduction and internal fixation with a laterally based locking plate will provide stable fixation of the distal femur fracture and allow the patient to have early mobilization and the ability to return to normal pre-injury activities. The primary risks are nonunion and hardware irritation. Advancements in locking constructs, by design or technique, provide multiple options to potentially reduce the risk of nonunion, but no definitive ideal construct exists. A large prognostic study attempted to define risk factors for locked plating failures and found that open fractures, diabetes, smoking, higher BMI, and shorter plate length were risk factors [22]. Plates with less than eight holes proximal to the fracture were a risk factor that could be adjusted by the surgeon. Another study found that open fractures with Gustilo/Anderson III grades and any fractures treated with a traditional open approach versus submuscular minimal invasive approach had higher nonunion rates [23].

External Fixation

AC is hemodynamically stable, has a closed fracture, and is without other injuries, so there is little indication for either temporary or definitive external fixation. If this injury was a severe open fracture, or if this were a polytrauma patient who required a delay in fixation, a temporary external fixator could be beneficial. A study which evaluated 16 distal femur and 36 proximal tibia high-energy fractures concluded that initial treatment of these periarticular knee fractures with bridging external fixation followed by planned conversion to internal fixation is a safe option with a 91%

healing rate and a deep infection rate of 16% [24]. It should be noted that in this study, the average time between the placement of external fixation and definitive fixation was 5 days with a range of 1–23 days. Although the use of an external fixator for definitive management of distal femur fractures is not common, it is an option in extreme cases, such as those that involve gross contamination, severe soft tissue injury, or vascular injury. A retrospective study, which evaluated 16 type C3 distal femur fractures treated using limited open reduction and internal fixation of the articular surface and tensioned wire circular external fixation of the metaphysis to the shaft, found that all 16 fractures healed within an average of 24 weeks. These patients had multiple complications including infection, mal-reduction, and decreased range of motion of the knee [25]. The authors concluded that this technique is recommended only for salvage of those type C3 distal femur fractures that cannot be stabilized with traditional ORIF secondary to severe comminution or because of extensive soft tissue injury [25]. In another study of 13 patients with supracondylar femur fractures treated with limited internal fixation and an external fixator, Marsh and colleagues concluded that in cases of severely comminuted open wounds, poor local skin, or multiple other injuries, or in cases where vascular repair has proceeded fracture fixation, the use of an external fixator was beneficial and outweighed the risks of such use [26]. Ali and Saleh [27] conducted a study of 13 patients with isolated distal femoral fractures treated with limited internal fixation and an Ilizarov ring external fixation and noted similar results to Marsh and colleagues. It should be noted, however, that these patients had an infection rate of 1–10% and significant knee stiffness that often required quadricepsplasty for decreased range of motion of the knee [27].

Intramedullary Nail

Intramedullary nailing is another treatment option for distal femur fractures. Whether an antegrade nail or a retrograde nail is better for treatment of a distal femur fracture has not fully been answered in the literature. For femoral shaft fractures, the outcomes of retrograde and antegrade intramedullary nailing have been proven to be similar [28]. In a retrospective study evaluating 41 distal femur fractures treated with a retrograde nail (21 cases) or an antegrade nail (20 cases), the authors did not identify any significant difference in patient outcomes such as femoral length, torsion, mechanical axis deviation, or functional outcomes between the patients treated with antegrade or retrograde nailing [29]. The one outcome variable in which there may be an advantage to using a retrograde nail compared to an antegrade nail is angular alignment. A study evaluating angular alignment after intramedullary nailing of a femoral shaft demonstrated that 11% (21 of 183) of femurs treated with an antegrade nail were malaligned compared to 7% (12 of 172) of femurs treated with a retrograde nail [30].

Several studies have evaluated the use of a retrograde femoral intramedullary nail for the treatment of a distal femur fracture [31, 32]. In a large meta-analysis of 544 distal femoral fractures, both extra-articular and intra-articular, the use of retrograde nailing for distal femoral fractures resulted in a mean union time of 3.4 months and a rate of union of 96.9% [33]. Furthermore, the mean range of knee motion was 104.6° [33]. The complications reported included knee pain in 16.5% and malunion in 5.2% [33].

Retrograde femoral nails, however, can be associated with several complications including intra-articular damage, knee stiffness, patellofemoral pain, and possible septic arthritis of the knee if the operative wound were to become infected. It should be noted, however, that most of these complications such as articular damage are associated with technical errors that could be avoided with attention to surgical technique, and other complications, such as knee stiffness and septic arthritis, have a very low incidence [28, 34].

As the distal femur is metaphyseal, the nail cannot be relied on to reduce the fracture; therefore, the use of blocking screws could serve to minimize the risk of malunions by directing the nail path and improving the reduction. In a series of eight patients who had a retrograde nailing performed with the use of blocking screws, Ostrum demonstrated success using blocking screws with retrograde femoral nailing to aid and reduce the distal femur fracture [35]. Furthermore, the authors also demonstrated that blocking screws provided additional stability to the intramedullary nail construct [35]. Another way to increase the strength of the construct of the retrograde nail, particularly in osteoporotic bone, is to use locked and/or multiplanar distal screws, as was shown in a cadaver study [36]. As noted previously, antegrade nailing is an acceptable treatment for distal femur fractures; however, if an antegrade nail is chosen, one must confirm that the fracture is greater than 3 cm proximal from the more proximal of the two distal locking screws, as this has been shown to decrease probability of failure in a biomechanical study [37].

Retrograde intramedullary nailing has been compared to other implants used for the treatment of distal femur fractures. In a study that evaluated 39 distal femur fractures (21 without intra-articular extension and 18 with intra-articular extension) in which an equal proportion of each fracture pattern was treated with either a LISS plate or a retrograde nail, no significant difference was noted with regard to union rate, range of motion of the knee, malalignment, infection, or implant failure at 1-year follow-up, though the study was underpowered [38]. Another study evaluating retrograde intramedullary nails versus locked plates in periprosthetic fractures above total knee arthroplasty found a higher failure rate and higher nonunion rate in the locked plating group [39]. Two studies, one a systematic review [40] and one a meta-analysis [41], have looked at periprosthetic distal femur fractures. The systematic review found nonunion rates of 8.8% and 3.6% and second surgery rates of 13.3% and 9.1% for locked plates and retrograde nails, respectively [40]. These differences were not statistically significant. The malunion rates however were statistically different, 7.6% versus 16.4% for locked plates and retrograde nails, respectively [40]. The meta-analysis looked at clinical outcomes, nonunions, and secondary surgeries. It found that these were similar between locked plating and retrograde intramedullary nailing.

Based on the evidence, the use of an intramedullary nail will provide stable fixation of the distal femur fracture in an effective manner, in order to allow the patient to have early mobilization and the ability to return to normal pre-injury activities.

Arthroplasty

Several authors have described the use of total knee arthroplasty in certain cases of acute distal femur fractures. Bell and colleagues reported having success in treating 13 supracondylar femur fractures in elderly patients with osteoporotic bone using a modular total knee system [42]. These findings were similar to those described by Freedman and colleagues, who, in a series of five patients, recommended this technique in patients who are elderly and have a highly comminuted distal femur fracture [43]. Additionally, Bettin and colleagues reported on 18 patients without prior arthroplasty treated with distal femoral replacement. All patients were extremely or very satisfied, and 12 of the 13 with available data returned to baseline functional status [44]. The use of a total knee arthroplasty or distal femoral replacement for an acute supracondylar femur fracture in the elderly is potentially an option; however, the evidence to support such an alternative is limited.

Literature Inconsistencies

The major challenge throughout the literature addressing treatment of distal femur fractures is the lack of randomized prospective controlled trials. The majority of the evidence is driven by retrospective cohort studies or at best prospective cohorts. More prospective randomized data are needed to better guide decision-making. There is currently an OTA-funded multicenter randomized trial of locked plates vs retrograde nails being carried out, so this answer may be forthcoming.

Evidentiary Table and Selection of Treatment Method

The key studies important to the treatment of AC are noted in Table 19.1 [10–12, 17]. Based on the literature, the authors feel that the best treatment

Table 19.1 Evidentiary table: A summary of the quality of evidence for plate fixation of distal femur fracture

Author (year)	Description	Summary of results	Level of evidence
Ostrum et al. (1995) [10]	Nonrandomized prospective cohort	30 distal femur fractures were treated utilizing a single lateral incision, indirect reduction, lateral plating, and no bone graft. 86.6% of patients had excellent and satisfactory results and 29/30 patients healed	II
Bolhofner et al. (1996) [11]	Nonrandomized prospective cohort	57 distal femur fractures were treated with ORIF, utilizing indirect reduction and no bone grafting or dual plating. Average healing time was 10.7 weeks. 84% of patients demonstrated good to excellent results	II
Henderson et al. (2011) [12]	Meta-analysis	479 nonperiprosthetic distal femur fractures were treated with locking plates. Nonunion rate 0–17% and delayed unions of 3–15%	I
Cots (2016) [17]	Prospective RCT	52 patients with OTA 33A1 or 33C1 randomized to get LISS or DCS plating. Higher rate of complication and reoperation in LISS vs DCS (52% vs 91%). Concluded fixed angle bicortical fixation better	I

in this case would be open reduction and internal fixation utilizing a single lateral approach and a locking plate.

Definitive Treatment Plan

The overall goal of open reduction and internal fixation utilizing a locking plate is to reconstruct the articular surface and to attain and maintain normal anatomic alignment compared to the contralateral femur. However, lag screw fixation of the intra-articular fracture and retrograde nailing is also a reasonable option.

Prior to positioning, one can obtain a contralateral femur rotational profile. This is done with the patient in the supine position with the patella directly anterior. A fluoroscopy view provides an AP image of the contralateral hip with the leg in maximum internal rotation and with the patella anterior. The amount of the lesser trochanter that is visible in these positions is important in assessing rotation of the injured limb.

The authors favor placing the patient supine on a radiolucent table without traction, with a bump under the ipsilateral buttock. In very obese patients, lateral positioning can be considered. This allows soft tissues to more effectively fall away from the surgical approach. The entire operative leg is prepped and draped.

An extensile anterolateral approach to the distal femur is utilized. The incision is made beginning at the level of Gerdy's tubercle, extending proximally and centered over the femur for the entire proximal extent needed. When visualization of the articular surface is required, as in this case, a minor modification curves the incision anteriorly toward the lateral aspect of the patella and then back posteriorly to the mid-axis of the femur. The IT band is divided, and the joint capsule is identified. As this patient has an intra-articular fracture, visualization of the articular surface is recommended in order to confirm that the joint is appropriately reduced and stabilized. In order to obtain a reduction of a displaced articular injury, reduction aids, such as Schanz pins, can be used to reduce any sagittal rotational deformity typically seen with a simple sagittal articular split. Once reduction of the femoral condyles has been achieved, a periarticular reduction clamp is placed on the medial and lateral condyles to compress across this fracture. At this time, lag screw(s) (3.5 or 4.5 mm) are placed from lateral to medial to stabilize this intra-articular split. Care and planning should be utilized to confirm that the screws will not hinder future plate placement, and one should confirm that no screw has penetrated the joint. After the intra-articular component is stabilized, the distal femur fracture is treated as an OTA type A fracture focusing on reducing the distal femoral block to the proximal femoral shaft, hence restoring overall alignment.

The distal fragment is reduced in relation to the proximal femur using several techniques. These techniques include the use of a supracondylar bump in order to correct the hyperextension of the distal fragment, which is often seen with this fracture, manual traction which will assist in the correction of the length and varus/valgus alignment, the use of manual manipulation to correct deformity, and other reduction maneuvers to aid in the reduction. Once acceptable alignment, rotation, and length have been established, a locking distal femoral plate is inserted through the distal portion of the incision and slid proximally along the lateral femur in a submuscular fashion in order to maintain the soft tissue envelope around the femur. Once plate position is confirmed, the plate is secured to the femur in standard fashion.

The patient's weight-bearing should be protected secondary to the articular injury; however, knee range of motion should be started as soon as possible.

Predicting Long-Term Outcomes

The long-term outcomes for these patients are mixed. In a study of 29 patients with a minimum of 10-year follow-up, Pettine noted degenerative arthritis developed in patients whose fractures had healed with articular incongruity, had a valgus deformity of greater than 15°, had any amount of varus deformity, or had a loss of normal mechanical axis [45]. Bolhofner and colleagues reported that knee stiffness and loss of range of motion may develop with immobilization, and this often contributes to poor outcomes [11]. Furthermore, the use of CPM machines did not appear to improve range of motion [11]. In a study of 59 supracondylar femur fractures, the authors concluded that the restoration of the coronal plane alignment is more difficult to restore than the sagittal plane and rotational alignment and that this coronal plane alignment is the most crucial to overall outcome [46]. In a study of 23 distal femur fractures treated with either open reduction and internal fixation or intramedullary nailing, functional outcomes were impaired with low SF-36 scores that were approximately two standard deviations below the US population normal [47]. Furthermore, only 9% of patients were pain-free at final follow-up [47]. Also, although 50% of these patients had significant posttraumatic arthritis at approximately 7 years following their index operation, it was uncommon that any of these patients had subsequent total knee replacements [47]. This finding was also confirmed in another long-term follow-up study of patients with intra-articular distal femur fractures treated with ORIF. The study including 32 patients demonstrated that at a mean of 14-year follow-up, 81% of patients did not have any pain in the treated limb, and the average knee range of motion was 118° [47]. Furthermore, although 36% of these patients demonstrated moderate to severe osteoarthritis, 72% of these patients had good to excellent functional results [47].

Finally, distal femur fractures in the elderly patient may have implications on mortality. In a study of 92 patients older than 60 years who sustained a fracture of a native distal femur (nonperiprosthetic), Streubel and colleagues demonstrated a 30-day mortality rate of 2%, a 6-month mortality rate of 13%, and a 1-year mortality rate of 23% [48]. This mortality rate is comparable to the published mortality rate for patients with hip fractures. Furthermore, these authors demonstrated that surgical delay greater than 4 days increased the 6-month and 1-year mortality rates compared to those who had surgery within 48 h of admission [49]. Another factor that has been shown to affect morbidity and mortality in the geriatric population after hip fracture is the time to weight-bearing and early mobilization. A study on 532 hip fractures in patients over the age of 50 found that increased total immobility was associated with increased mortality at 6 months and worse functional outcomes at 2 months [50]. Kamel's study found that in the acute postoperative period, time to ambulation was in an independent risk for the development of pneumonia (1.5 OR [odds ratio]/day, *p*, 0.001), new onset delirium (1.7 OR/day, *p*, 0.001), and for prolonged length of hospital stay

[51]. Another study looking at 60 hip fractures comparing early versus delayed ambulation found that at 1 week post-surgery, the early ambulation group walked further than those in the delayed ambulation group ($p = 0.003$), required less assistance to transfer ($p = 0.009$), and were more likely to be discharged directly home from acute care setting (26.3% vs 2.4%) [52].

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20 Knee Dislocations

Mahesh Kumar Yarlagadda, Frank R. Avilucea, Samuel Neil Crosby Jr, Manish K. Sethi, and William T. Obremskey

MS: 33-Year-Old Male with Knee Pain

Case Presentation

MS is a 33-year-old male who presents to the emergency department after sustaining a motorcycle accident in which he slid on a patch of ice and lost control of his motorcycle. Upon presentation to the emergency department, his chief complaint is of right knee and leg pain. On primary survey, he demonstrates a GCS of 15, a patent airway, and is hemodynamically stable. On secondary survey, no gross deformity is noted to his right lower extremity.

His past medical history is negative; he takes no medications and has no allergies.

On physical examination, there are no open wounds on his thigh, knee, or leg. MS has an effusion of the right knee. Passive range of motion is from 0° to 90° of flexion and is painful. Examination of the right knee demonstrates a positive anterior drawer, a positive posterior drawer, and a positive Lachman sign. The dial test is equivocal secondary to pain. Gross instability is noted to varus and valgus stress at 0 and 30° of flexion. The patient' s dorsalis pedis and posterior tibialis pulses are palpable but decreased compared to the contralateral extremity. Sensation to light touch is intact in all dermatomal distributions and is equal to the contralateral extremity. No pain is elicited with passive stretch of toes. Compartments are firm but compressible. No pain or deformity is noted in the thigh, the ankle, or the foot.

Radiographs and MRI of the left knee are demonstrated in Figs. 20.1a, b and 20.2a–d.

Interpretation of Clinical Presentation

The patient presents with a clinical picture consistent with a knee dislocation. The mechanism of injury involves a motorcycle accident, which sug-

M. K. Yarlagadda (✉)
Department of Orthopedic Trauma, Vanderbilt University Medical Center, Meharry Medical College, Nashville, TN, USA
e-mail: myarlagadda15@email.mmc.edu

F. R. Avilucea
Department of Orthopedic Surgery, Division of Orthopedic Trauma, University of Cincinnati Medical Center, Cincinnati, OH, USA

S. N. Crosby Jr
Elite Sports Medicine and Orthopedic Center, Nashville, TN, USA

M. K. Sethi
Department of Orthopedic Surgery and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA

W. T. Obremskey
Department of Orthopedic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA

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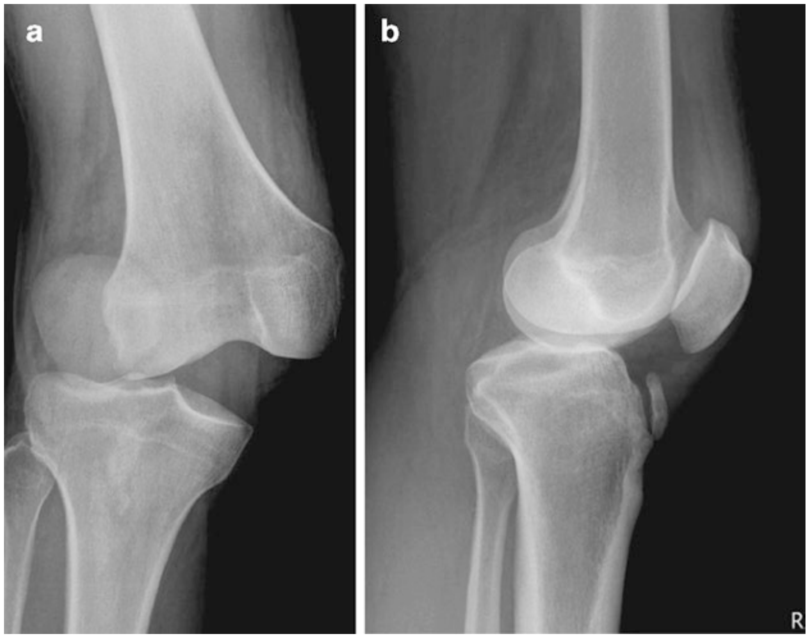

Fig. 20.1 (**a**) AP radiograph knee (**b**) Lateral radiograph knee

gests a high energy. He complains of right leg pain, but no deformity is noted on initial survey. On exam, he has laxity to anterior and posterior drawer, as well as varus and valgus stress. This suggests that he has likely injured both cruciate ligaments as well as both collaterals. In 1996, O'Shea and colleagues studied the reliability of physical exam findings in making the diagnosis of acute knee injuries [1]. They prospectively made a diagnosis on 156 knee injuries based only on history, physical exam findings, and plain radiographs. These diagnoses were compared with intraoperative findings to determine reliability. Their series included 67 ACL injuries and four PCL injuries. They diagnosed ACL injuries with 97% sensitivity and 100% specificity. PCL injuries in their series were diagnosed with 100% sensitivity and 99% specificity. However, when injuries were complicated by a second ipsilateral knee injury, such as an additional ligamentous or meniscal injury, their diagnostic accuracy declined to 54%.

Figure 20.1a, b is an AP and lateral of the right knee. No fractures are observed, but the knee has an effusion, radiographically. On the AP, the tibia is subluxated laterally and in varus, indicating ligamentous injury. This is further verified by the coronal MRI image seen in Fig. 20.2a–d, which demonstrates an avulsion of the medial collateral ligament off of the femur as well as a mid-substance tear of the lateral collateral ligament structures.

The use of MRI has greatly improved the ability to diagnose knee dislocations, and the authors believe that the literature suggests that MRI is now the gold standard in diagnosis. In 1996, Twaddle and colleagues compared clinical findings to MRI in the ability to accurately diagnose injuries in knee dislocations [2]. The investigators utilized intraoperative findings as the gold standard to compare these two methods. They found MRI to be 100% sensitive and 100% specific in diagnosing ACL, PCL, and patellar tendon injuries. Furthermore, when considering all ligaments/capsular injuries, they found MRI to be 85–100% accurate as compared to clinical findings, which were found to be 53–82% accurate.

In terms of the initial management of the patient, the first action that should be taken is to reduce the knee joint through a closed reduction maneuver, although there is no direct literature that specifically addresses closed reduction of knee dislocations. A joint reduction can often be

Fig. 20.2 (**a, b**) T1 sagittal MRI knee (**c**) T2 sagittal MRI knee (**d**) T2 coronal MRI knee

achieved by direct manipulation of the lower extremity in order to obtain normal anatomic alignment. This will provide a more accurate assessment of neurovascular status and will facilitate immobilization and transport of MS. Special attention should be paid to the medial skin. Puckering or dimpling of the skin over the medial joint line has been described in irreducible knee dislocations and often represents the buttonholing of the medial femoral condyle through the medial capsule or structures [3].

Ligamentous knee injuries are a concern with high-energy orthopedic trauma; however, there are many discrepancies in the literature surrounding the management of these injuries due to their low incidence of occurrence and high incidence of being missed at initial presentation. These injuries are often missed on initial assessment due to spontaneous reduction of the joint, distracting injuries, and absence of abnormality on initial review of plain radiographs. For example, Walker and Kennedy found that the incidence of occult ligamentous knee injuries can be as high as 48% in patients with femur fractures. They point out that the diagnosis of these ligamentous injuries is often delayed by months [4]. Moreover, despite the fact that knee dislocations and bicruciate knee injuries can present after spontaneous reduction, spontaneous reduction does not decrease their morbidity. In a retrospective review of 50 patients with knee dislocations, Wascher and colleagues found that bicruciate injuries that spontaneously reduced were equivalent to "classic" knee dislocations (three ligaments injured) with regard to injury severity, major vascular injury, and mechanism [5].

The clinical presentation of patients with knee dislocations can often be complicated by popliteal artery injuries and injuries to the common peroneal nerve. With regard to MS, it is noted that he has diminished pulses in his right leg. Concomitant popliteal artery injury is a well-established complication of knee dislocations. In a retrospective study of 245 knee dislocations (241 from a literature review; 4 patients gathered in the study), Green and Allen found the incidence of popliteal artery injury to be as high as 32% [6]. Popliteal artery injury can be a devastating complication of these injuries if left untreated. Data from the Lower Extremity Assessment Protocol (LEAP) study of severely injured lower extremities showed that approximately 20% of patients who present to a level one trauma center with a dysvascular limb will need an amputation [7]. This study also demonstrated that this rate rises with increased warm ischemia time. Thus missing these injuries on initial evaluation places patients with knee dislocations at an increasingly high risk for losing their limb.

During evaluation of MS in the emergency department, one must obtain either an ankle-brachial index (ABI) examination or computed tomography angiography (CTA) given his knee dislocation. One evidence-based change in the standard of care of these injuries has been the move from routine angiography to selective angiography. Physical examination is the first step in discovering popliteal artery injuries. In a prospective outcome study involving 134 dislocated knees, Stannard and colleagues found that a thorough physical exam had a 90% positive predictive value, with 100% sensitivity and 99% specificity [8]. However, the clinical utility of the protocol set forth by this study, which uses serial physical exams performed by the same surgeon, has been questioned because of the labor-intensive nature of having one person perform multiple serial exams during the initial period after injury. In addition to a thorough physical exam, a quick assessment for vascular injury that can be done at the bedside is the ABI. In a prospective study of 38 patients, with knee dislocations, an ABI of less than 0.90 predicted a vascular injury in 11 patients, with 100% sensitivity and 100% specificity [9]. In the past decade, CT angiography has replaced conventional angiography in detecting vascular injuries in the extremities as a less invasive method of detecting these injuries and is a possible screening exam for at-risk limbs or as a diagnostic tool for abnormal ABIs [10].

The preponderance of the published literature indicates that every patient who presents with an obvious knee dislocation, history of a knee dislocation, or physical exam that indicates a knee dislocation requires a careful neurologic and vascular examination. Even if physical findings such as normal pulses are present, the patient needs some type of documentation of vascular status due to the challenge of the same provider performing serial exams over the next 24–48 h. An ABI measurement can be done at any facility as a screening exam with a high sensitivity of detection of an operable vascular injury. If the ABI ratio is less than 0.9, one needs to consider another imaging study, such as a CT angiogram or arteriogram, as this is predictive of a vascular injury requiring repair [9].

While the patient's neurological exam is normal, one must consider the peroneal nerve. Peroneal nerve injury is another complication associated with knee dislocations. In a case series of 55 dislocations of the knee, Niall and colleagues evaluated the incidence of peroneal nerve injuries [11]. They found peroneal nerve injuries in 14 of 55 patients (25%) when all knee dislocations were considered. They found a higher incidence of nerve injuries in knees with bicruciate injuries and concomitant posterolateral corner disruptions: 14 of 34 patients (41%). The incidence of peroneal nerve injuries in these injuries is most often quoted to be 20–30%.

Finally, in terms of initial management of MS, one must consider immobilization of the extremity. Historically, patients with knee dislocations have been placed either in a cylinder splint, a knee immobilizer, a hinged knee brace, or an external fixator upon arrival to the hospital. If initial reduction is successful and the reduction is stable, a splint or hinged knee brace is likely adequate for immobilization until definitive surgery can be performed. A recent protocol, suggested by Levy and associates and used on nine consecutive patients successfully, recommends placement of an external fixator immediately in cases of knee dislocations with a vascular injury or open knee dislocations [12]. Furthermore, they recommend placement of an external fixator in cases where there is inability to maintain a reduction adequately in a brace or splint and in cases where the patient is unable to tolerate mobilization in a brace. Although this study has a relatively low number of patients, it provides an initial protocol to follow when considering whether a splint or hinged knee brace would be appropriate. Ultimately, placement of an external fixator should be guided by necessity. For example, external fixation may be appropriate for a patient requiring multiple trips to the operating room for debridement of wounds or surgical treatment of ipsilateral injuries on the limb.

Declaration of Specific Diagnosis

MS presents with a high-energy injury consistent with a multiligamentous knee injury with damage to his ACL, PCL, MCL, and posterolateral corner with no neurologic or vascular injury.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Detect limb-threatening injuries
2. Restore stability of the knee
3. Allow for stable, concentric early motion to prevent arthrofibrosis and end-stage arthritis of the knee
4. Return to normal life activities

Treatment options include:

1. Nonoperative management
2. Open primary repair
3. Delayed arthroscopic reconstruction
4. A staged approach using a combination of primary repair and reconstruction

Evaluation of the Literature

In order to identify the relevant publications on knee dislocations, Medline and PubMed searches were performed. The term "knee dislocation" was queried, and the search was limited to 1970 to 2011. A total of 2176 articles were identified. These were then searched according to different subheadings including "surgical treatment," "nonoperative treatment," "primary repair," and "reconstruction." A total of 187 articles were read and reference lists were reviewed. We selected prospective or comparative articles and retrospective articles that addressed a specific question in management if no prospective or comparative data were available. We also included a consensus guideline. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Outcome Measurements

In terms of understanding the literature regarding ligamentous knee injuries, one must understand the outcome measurements. Clinical outcome measurement includes range of motion, ligament stability, and revision rate due to failure of repair or reconstruction. The most commonly used functional outcome measurements in studies involving acute knee dislocations are the Lysholm knee score, the Tegner activity scale, and the IKDC (International Knee Documentation Committee) score [13–19]. The Lysholm knee scale assesses functional knee outcome based on limp, swelling, locking, pain, support, instability,

Table 20.1 Wascher modification of Schenck classification

KD I	Knee dislocation with both cruciates intact
KD II	Bicruciate injury with both collaterals intact
KD III	Bicruciate injury with one collateral torn
KD IV	Bicruciate injury with both collaterals torn
KD V	Knee dislocation with periarticular fracture

Used with permission of Elsevier from Wascher [20]

stair climbing, and squatting. A score of 0–100 is given with 95–100 being excellent, 84–94 good, 65–83 fair, and 64 and below poor. The Tegner activity scale assesses a patient's activity level in order to negate the confounding effect of a less-active patient versus a more-active patient on Lysholm knee score. Tegner knee scores are based on the activity level of a postoperative patient. It scores patients on a scale of 0–10 with a score of 10 representing patients competitive in high-demand sports at an elite level, a score of 6 being allocated for patients playing recreational sports, and finally 0 being a person on disability or sick leave.

The IKDC score is based on a series of questions about symptoms, sports activities, and daily function. It gives a score of 18–100 with a score of 100 as being asymptomatic with full return to sports and no limit in daily activities.

The most common classification system for knee dislocations is the Wascher modification of the Schenck classification [20]. The modified Schenck classifies the dislocation according to injury pattern of the knee ligaments (Table 20.1) [20]. This chapter will mainly address the management of KD III–V, which are knee injuries with three or more ligament injuries.

Detailed Review of Pertinent Articles

Nonoperative Versus Operative Management

Until the past two decades, nonoperative treatment was thought to be a valid option in closed, reducible knee dislocations without vascular injury or significant fracture. For example, Taylor and associates published a case series of 42 knee dislocations, with 16 patients treated operatively and 26 patients treated nonoperatively. At the time of the study, nonoperative management was the preferred modality of treatment, and all cases treated operatively were performed out of "necessity", either for an irreducible joint, open injury, neurovascular injury, or associated fracture. Nonoperative treatment consisted of brace or casting with delayed motion. Taylor found better outcomes in the nonoperative group when assessing stability, movement, and pain. It should be noted that the operative group underwent multiple different operations, and treatment was not standardized [21].

Current literature on knee dislocations favors operative treatment compared to nonoperative management. In 2001 Dedmond and Almekinders published a meta-analysis comparing operative to nonoperative treatment in knee dislocations [13]. They compared 132 knee dislocations treated operatively to 74 treated nonoperatively. They found a range of motion of 123° in the operative group compared to 108° of motion in the nonoperative group. They also found significantly higher Lysholm scores in the knees treated with an operation, 85.2 compared to 66.5, indicating significantly less disability. However, there was no demonstrated significant difference between the two groups in return to work, return to athletics, or knee instability.

Richter and associates published another study that directly compared operative versus nonoperative treatment of multiligament knee dislocations [14]. It was a retrospective cohort study comparing 59 patients undergoing repair or reconstruction to 18 patients treated nonsurgically. In their study, they found significantly better Lysholm and Tegner scores in the operative group, 78 versus 65 (Lysholm) and 4.0 versus 2.7 (Tegner), indicating less disability and greater return to activity.

Frosch and associates conducted a meta-analysis including nine studies evaluating 200 knees across three comparison groups: patients treated without surgical intervention, patients treated by sutures, and patients undergoing reconstruction of the ACL/PCL. The group found that 70% of patients undergoing no treatment of

ACL/PCL experienced poor to moderate results, whereas patients treated by sutures of the ACL/PCL demonstrated a significantly higher proportion of excellent to good results (40% and 37.5%, respectively). Furthermore, patients undergoing reconstruction of the ACL/PCL ($n = 75$) experienced excellent to good results (28% and 45%, respectively). However, no significant difference was observed when comparing sutured ligaments versus reconstructed ligaments. The group determined that the outcome depended considerably on Schenck classification [22].

At the time of surgical treatment with repair or reconstruction, we do not recommend the use of a tourniquet if a vascular injury has occurred.

Early Repair Versus Late Repair

The majority of the literature on timing of operative intervention in knee dislocations favors early, within 6 weeks, over late repair or reconstruction, with resulting higher subjective knee scores and activity ratings [15, 16].

One study that investigated surgical timing of these injuries was done by Harner and associates [15]. This was a retrospective cohort study of 31 dislocated knees treated in a non-emergent setting. Nineteen of these knee injuries were treated within 3 weeks of the trauma, and the other 12 were treated on a delayed basis at an average of 6.5 months after the index injury. The average Lysholm knee scores of the group treated within 3 weeks was 91, and the average of the delayed surgical group was 80. Furthermore, the average Knee Outcome Sports Activities Scale scores were much higher in the early treatment group, 89 compared to 69. However, they found knee range of motion to be similar and acceptable in both groups.

Another study looking at optimal timing of operative fixation of knee dislocations was done by Liow and associates [16]. They presented a series of 22 dislocated knees, with eight treated in the acute phase of less than 2 weeks and 14 treated greater than 6 months after the injury (range 6–72). Injuries were treated with a combination of repair and reconstruction. They found that both Lysholm scores and Tegner activity ratings were higher in the early treatment group, 87 versus 75 and 5 versus 4.4. They also did instrumented testing of knee stability and found that the ACL reconstructions done acutely had less anterior tibial translation than those undergoing delayed treatment. Like Harner and associates, they also found that knee range of motion was not significantly different between the two groups.

An alternative method of timing these operations is to separate the repair/reconstructions of the damaged ligaments into a staged procedure. In this approach, the collateral ligaments are either repaired or reconstructed acutely, usually in the first week, and the ACL ± PCL are reconstructed later, usually at around 6 weeks. This method allows surgeons to do an open approach to repair or reconstruct the damaged collateral ligaments early, when the zone of injury is fresh, and it allows the capsule time to heal for the arthroscopic portion of the procedure which can be done at around 6 weeks [23].

Another alternative is reconstructing the PCL early to restore the central pivot, then delaying the ACL and collateral reconstruction for a second stage. In 2002, Ohkoshi and associates published a series of 13 knee dislocations treated with this method [24]. These patients had good range of motion with full extension and a mean of 126.7° active range of motion and 139.5° of passive flexion. These knees were also found to have adequate stability. However, standardized outcome measures were not tested in these patients. Further studies on outcomes of these knees are needed for validation of this method.

Open Versus Arthroscopic Cruciate Repair

Open ligamentous repair or arthroscopic repair remains controversial. Both approaches offer advantages and disadvantages. An open approach to these injuries is advantageous for addressing bucket handle meniscus tears, patellar tendon avulsions, quadriceps ruptures, displaced collateral avulsions, and capsular tears. One frequent concern for open repair versus arthroscopic reconstruction is postoperative arthrofibrosis. However, a case series with open repair and early aggressive modern rehabilitation programs demonstrates acceptable outcomes. Owens and associates published a series of patients repaired primarily in 2007, with a mean arc of motion of 119.3° and no incidence of late loosening that required reconstruction [17]. They retrospectively reviewed 28 acutely dislocated knees in 25 patients undergoing open repair of torn ligaments mostly within 2 weeks of the index injury and, with 2-year follow-up data, demonstrated good mean Lysholm (89) and Tegner (4.4) scores. The main complication of these patients was arthrofibrosis requiring arthroscopic lysis of adhesions in five patients (19%).

Other authors have shown good results with arthroscopic treatment of the ACL and PCL in knee dislocations. Some authors advocate that an arthroscopic approach leads to less arthrofibrosis and fewer wound complications due to less dissection [25], although no definite data have proven that either approach is superior. Fanelli and Edson [26] reported a prospective cohort of 35 combined ACL/PCL injuries with 34 knees with an ACL/PCL/collateral injury. These patients were treated with arthroscopically assisted reconstruction of cruciate ligaments and open reconstruction of collateral ligaments, and all had a minimum of 2-year follow-up. Their cohort of patients had an average Lysholm score of 91.2 and an average Tegner score of 5.3.

Kohl and coworkers (2014) have developed a surgical technique for ACL repair as an alternative to conventional arthroscopic repair. Dynamic intraligamentary stabilization (DIS), a method that utilizes a braided wire inserted from the anteromedial aspect of the proximal tibia, through the middle of the torn ACL, anchored to the lateral aspect of the femur [27]. Kohl and coworkers (2015) presented this novel technique, developed at their institution, to determine the clinical and radiological outcomes of knee dislocations surgically treated in this manner. Between 2009 and 2012, 35 patients were surgically treated with the DIS technique and evaluated clinically and radiologically with a mean follow-up of 2.2 years. The cohort experienced a mean Lysholm score of 90.8 and Tegner score of 6, with an IKDC score of B in 29 (83%) patients and C in 6 (17%) of patients. Two of the 35 patients included in the study cohort required a secondary operation. The group concluded that early, single-stage ACL reconstruction utilizing the DIS technique is capable of achieving beneficial results functionally without the requirement for grafting [28].

Repair Versus Reconstruction

Reconstruction of the ACL and PCL using allograft is a proven method of treating mid-substance cruciate ligament injuries and may also be used when the ligaments are avulsed off of bone. Wascher and associates published a series of 13 patients who underwent reconstruction of both the ACL and PCL after sustaining a knee dislocation [29]. The mean Lysholm score in these patients treated with reconstruction of both ACL and PCL was 88, demonstrating acceptable outcomes utilizing reconstruction. Mariani and associates retrospectively compared techniques using reconstruction and repair for ACL and PCL injuries in knee dislocations [18]. They reported 23 patients with knee dislocations, divided into three groups: one group undergoing primary repair of both ACL and PCL, another group undergoing ACL reconstruction with PCL repair, and a third group undergoing reconstruction of both ACL and PCL. They found similar outcomes in Lysholm knee scores in all three groups (84 in repair group, 86 in ACL reconstruction/PCL repair, and 85 in the reconstruction group). However, they did find a higher rate of flexion loss greater than 6° in groups undergoing primary repair (82% in repair group, 67% in ACL reconstruction/PCL repair group, and 33% in reconstruction group). Arthroscopic repair of PCL "sleeve avulsions" has also been recently reported [30].

Early repair of the posterolateral corner (PLC) historically has been recommended by Shelbourne and Klootwyk [31]. Due to risk of late loosening, reconstruction has been recommended in two studies and in a JAAOS review article [19, 32, 33]. One study showing higher failure rates in primary repair of the PLC was published by Stannard and associates in

2005 [19]. This study was a prospective cohort study that included 57 PLC injuries in 56 patients. Forty-four (77%) of these injuries were multiligamentous knee injuries. Patients were not randomized but were treated with either primary repair of the PLC ($n = 35$) or reconstruction using allograft ($n = 22$). This study found higher failure rates in primary repair than reconstruction (37% versus 9%). Lysholm scores were similar in the repair and reconstruction cohorts of the patients who did not fail (88.2 versus 89.6).

Levy and associates have also reported similar results in a study [32] comparing primary repair versus reconstruction of the posterolateral corner. Reconstruction was found to have a significantly lower failure rate than primary repair. This retrospective review involved 28 knees treated in a single-stage procedure. Failure rate of primary repair was found to be approximately 40%, and failure rate of reconstruction was found to be approximately 6%. Both IKDC scores and Lysholm scores were found to be equivocal: 79 and 85 in the repair group versus 77 and 88 in the reconstruction group, respectively. Both of these studies staged the repair of the collateral repair and the arthroscopic cruciate reconstruction. In the Levy study the procedures were staged an average of greater than 4 months. The results of early repair of collaterals combined with acute repair or reconstruction of cruciates are not known.

On the other hand, a retrospective study conducted by McCarthy and associates comparing repair versus reconstruction following posterolateral knee injuries suggests an alternative recommendation. The study evaluated a total of 26 knees, 17 reconstructions, and 9 repairs, to determine if a significant difference existed between those knees reconstructed versus those repaired. Reconstructions were evaluated at a mean postoperative time of 38 months and repairs at a mean of 42 months. Average Lysholm scores were 83 for both reconstructed and repaired knees, and average IKDS scores for reconstruction and repair were 68 and 71, respectively. Overall, the group observed no significant difference between postoperative evaluation for posterolateral knee injuries undergoing reconstruction versus repair, suggesting an inconclusive recommendation regarding PLC treatment [34].

Stannard and coworkers in 2012 conducted another retrospective analysis comparing the outcomes of repair to reconstruction in 73 knee dislocations involving posteromedial corner (PMC) injuries, which included both medial collateral and posterior oblique ligament injuries. Patients were followed for a mean of 43 months. Twenty-five patients had a PMC repair, with failure in 5 (20%) cases, whereas 48 patients had reconstruction with only 2 failures (4%). The group determined that reconstruction of the PMC using a technique that reestablished the MCL, POL, and semitendinosus yielded better stability than repair in patients experiencing similar injury [35]. This group also had a significant delay in the staged procedures.

Hinged External Fixator

Some surgeons advocate the placement of a hinged knee external fixator after reconstruction of the knee ligaments to provide stability but simultaneously allow for early motion. Stannard and associates performed a prospective case control study involving the placement of compass knee hinge (CKH) external fixators postoperatively [36]. In their study, they followed 39 knee dislocations undergoing reconstruction of all torn ligaments. Twelve of these were placed in a CKH and 27 were placed in a hinged knee external brace. They found that the patients placed in a hinged knee brace had a much higher ligament failure rate at 29% than patients placed in a CKH at 7%. However, they found that SF-36 scores were not significantly different in the two groups. Their group advocated the use of the hinged knee external fixators as they protect the ligaments while allowing for early postoperative knee range of motion. In the case of open knee ligamentous repair, postoperative hinged external fixators have not been investigated.

These data indicate that if reconstruction of all injured ligaments is utilized, surgeons should consider a hinged external fixator.

Literature Inconsistencies

Many inconsistencies remain in the literature over treatment of acute knee dislocations. Much of this is due to the relatively low incidence of these injuries and the bias of the treating physician. Because of this, a lack of randomized prospective data on these questions exists. Adequate results have been reported using different protocols and combinations of open versus arthroscopically aided treatment and repair versus reconstruction. The problem with many of these studies is both the lack of uniformity and the low number of patients in each study. The studies presented above vary widely on timing and staging of operative treatment. They also lack a uniform postoperative rehabilitation protocol. Many of the Lysholm and Tegner knee scores reported were obtained at different times. Moreover, most of the studies presented above include outcomes based on low numbers of patients, commonly between 20 and 50 patients.

What is required to definitively answer many of these questions is prospective studies looking at specific treatment options: in particular, open versus arthroscopic treatment and primary repair versus reconstruction. Studies involving multiple treatment centers may also be required in order to obtain adequate data on these injuries.

Evidentiary Table and Selection of Treatment Method

Table 20.2 [13, 15, 17, 19, 22, 26, 34, 35, 42] presents a summary of the quality of evidence for early operative open treatment of knee dislocations with reconstruction of the posterolateral corner.

The goal of treatment in MS is to restore stability and function of the knee. In the past 20 years with improved operations and postoperative rehabilitation regimens, the literature clearly demonstrates better outcomes with operative treatment as compared to nonoperative treatment [13, 14]. Timing of the operation should be based both on operative plan and stability of the patient. Although smaller series have shown adequate stability with chronic knee dislocations [37–39], the preponderance of data favors treating these injuries early, within 6 weeks [15, 16]. If an open approach is favored, it may be possible to treat the injury within 2 weeks; however, if an arthroscopic approach is favored, it may be prudent to wait 3–6 weeks to allow the capsule to seal and provide a favorable environment for arthroscopy.

However, if an arthroscopic approach to these injuries is favored, the literature clearly demonstrates that early repairs of the collateral ligaments followed by reconstruction of the cruciate ligaments lead to late loosening of the collaterals [19, 32]. If arthroscopic treatment of the cruciate ligaments is planned, the PLC should be repaired or reconstructed at the time of the cruciate reconstruction, as was recommended by the Knee Dislocation Study Group [33], and a hinged fixator should be considered to prevent late loosening. The advantages of this methodology include low risk of revision surgery or arthrofibrosis, minimal incisions, and literature of satisfactory results. Challenges are technical aspects of arthroscopic reconstruction, treatment of concomitant patellar tendon ruptures, complete avulsions and bucket handle meniscus tears, cruciate bony avulsions or articular fractures, and the cost and morbidity of hinged external fixators.

An open approach of repair and reconstruction of all structures is also an option. Advantages of this option include completion of treatment in the initial hospitalization period, no requirement for arthroscopic instruments, and ability to address all soft tissue and bony pathology (patella tendon tears, fractures, bucket handle meniscus tears, complete meniscus avulsions, cruciate ligament avulsions, and collateral ligament avulsions). Challenges of this strategy include the risk of arthrofibrosis, larger incisions, and risk of infection.

Predicting Long-Term Outcomes

Dislocation of the knee is a devastating injury that can have many long-term consequences. While operative treatment has improved outcomes, the majority of the studies listed above show Lysholm knee scores in the 75–90 range

Table 20.2 Evidentiary table: A summary of the quality of evidence for early operative open treatment of knee dislocations with reconstruction of the posterolateral corner

Author (year)	Description	Summary of results	Level of evidence
Dedmond et al. (2001) [13]	Meta-analysis	Compared 132 knee dislocations treated operatively to 74 treated nonoperatively. Lysholm knee scores, 85.2 in operative group compared to 66.5 in nonoperative Group	I
Frosch et al. (2013) [22]	Meta-analysis	Compared 27 nonsurgically treated, 40 sutured, and 75 reconstructed ACL/PCL injuries involving knee dislocations. Surgically managed patients had significantly better clinical outcomes	IV
Harner et al. (2004) [15]	Retrospective cohort study	Compared 19 knees treated early (within 3 weeks) to 12 treated delayed (average 6.5 months). Lysholm knee scores 91 in early group versus 80 in delayed group	III
Ibrahim et al. (2013) [42]	Case series	Reported a mean Lysholm score of 90 points in 20 patients treated by primary arthroscopic reconstruction at a mean follow-up time of 44 months	IV
Fanelli et al. (2002) [26]	Prospective cohort study	Reported 35 knees treated with arthroscopically assisted cruciate reconstruction with open collateral reconstruction. Average Lysholm knee scores 91.2	III
McCarthy et al. (2015) [34]	Retrospective cohort study	Compared 26 knees (17 reconstructed and 9 repairs) at a mean of 38 months for reconstructions and 42 months for repairs postoperatively. Lysholm scores, IKDC, and failures were not significantly different	IV
Owens et al. (2007) [17]	Retrospective cohort study	Reported 28 knees treated with early open primary repair of torn ligaments. Average Lysholm knee score 89.0	IV
Stannard et al. (2012) [35]	Retrospective cohort study	Compared PMC repair in 25 patients experiencing 5 (20%) failures versus reconstruction in 48 patients with 2 failures (4%)	IV
Stannard et al. (2005) [19]	Prospective cohort study	Compared 35 PLC repaired primarily to 22 PLC undergoing reconstruction. Primary repair with higher failure rates (37% versus 9%). Equivocal Lysholm knee scores	II

and Tegner knee scores in the 4–5 range. This correlates with a "good" outcome and possible return to recreational sports. The major challenge in treating these injuries is balancing stability of the knee with arthrofibrosis and stiffness. "Early" surgical treatment of these severe injuries is recommended. Also repair of all damaged structures in either a single procedure or shortly staged procedures is also recommended. Most reviews are recommending early repair of collateral ligaments, patella tendon avulsions, and displaced meniscal tears. Allograft augmentation of these structures has been proposed but not rigorously studied. Cruciate repair or reconstruction in a single procedure or staged procedures with open or arthroscopic techniques followed by early range of motion produces good results. If staged reconstruction is pursued, concurrent use of a hinged external fixator results in fewer ligament failures. A prospective randomized study on 103 knee dislocations found that use of the hinged external fixator as a supplement to reconstruction offers favorable results. In this study 79 dislocations were evaluated for a minimum of 12 months with the mean duration of follow-up being 39 months. In this study the patients who had supplemental placement of a hinged external knee brace had a higher failure rate compared to those who had supplemental treatment with a hinged external fixator (29% vs. 15%) [40].

Another factor that can influence outcome is the severity and type of injury. A recent study by Vallier and associates on 119 dislocations found that open knee dislocations had a significantly higher rate of amputation (26% vs 1.3%, $p < 0.001$). Vascular injury, more specifically popliteal artery injury was associated with a higher rate of amputation (31% vs. 3.2%,

$p < 0.001$), infection (37% vs 8%, $p = 0.002$), and DVT (32% vs. 8.8%, $p = 0.014$). Patients with wound infection were more likely to develop heterotopic ossification (36% vs. 9.4%, $p = 0.017$) and less knee motion (77.5° vs. 117°, $p = 0.049$). Finally this study found that an ISS greater than 19 was associated with less knee motion (97 vs. 121, $p = 0.029$) [41].

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21 Tibial Plateau Fractures

Jodi Siegel and Paul Tornetta III

AB: 55-Year-Old Female with Leg Pain

Case Presentation

AB is a 55-year-old female who presents to the emergency department with a chief complaint of right leg pain after being struck by an automobile while crossing the street. She denies any other pain or complaints. On primary survey she demonstrates a GCS of 15 and patent airway and is hemodynamically stable. Secondary survey demonstrates a gross deformity of the proximal aspect of the right leg.

On physical examination, the patient has palpable dorsalis pedis and posterior tibial pulses. There are no open wounds on the right leg. The patient's leg is swollen, but the compartments are compressible. Her sensation to light touch is grossly present in all dermatomal distributions. She has no pain elicited with passive stretch of the toes and is able to grossly dorsiflex and plantarflex her ankle and toes without any difficulty. No other injuries are noted in the ipsilateral thigh, ankle, or foot.

Radiographs and CT scan images of the right proximal tibia are demonstrated in the Figs. 21.1a, b, 21.2a, b, and 21.3a–h.

J. Siegel (✉)
Department of Orthopedics,
University of Massachusetts Memorial Medical Center,
University of Massachusetts Medical School,
Worcester, MA, USA
e-mail: Yoda5052@aol.com

P. Tornetta III
Department of Orthopedic Surgery,
Boston Medical Center, Boston, MA, USA

Interpretation of Clinical Presentation

The patient's mechanism, physical examination, and radiographs are consistent with an isolated bicondylar tibial plateau fracture. The tibia is shortened and malaligned. In addition to condylar widening, the lateral and central joint surfaces are depressed. The medial condylar fragment is a short segment, and her bone quality appears osteopenic. Given the history and the fracture pattern, vigilance must be exercised in looking for associated injuries, and a trauma consultation is appropriate to rule out non-orthopedic injury.

Although low-velocity injuries with minimal soft tissue compromise can undergo definitive open treatment early, significant injury to the soft tissue envelope should be expected in bicondylar fractures, fracture-dislocation patterns, and metadiaphyseal dissociations. Small wounds and subtle abrasions to the skin in the zone of injury,

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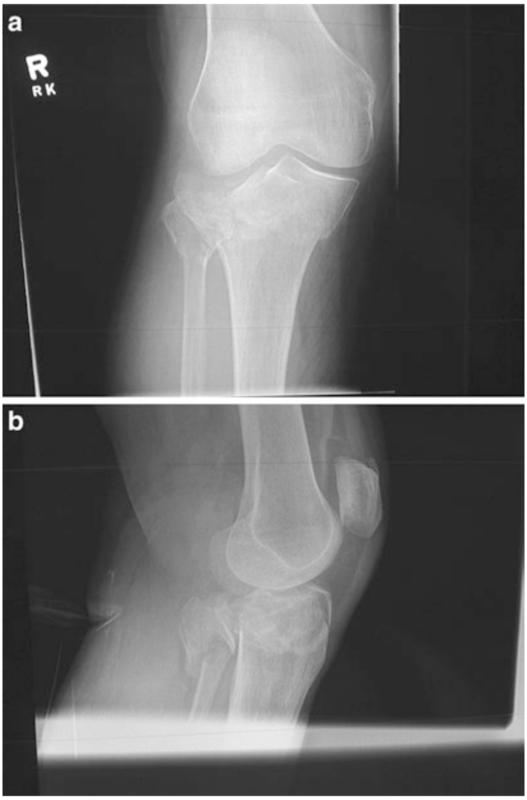

Fig. 21.1 (**a**) AP radiograph knee. (**b**) Lateral radiograph knee

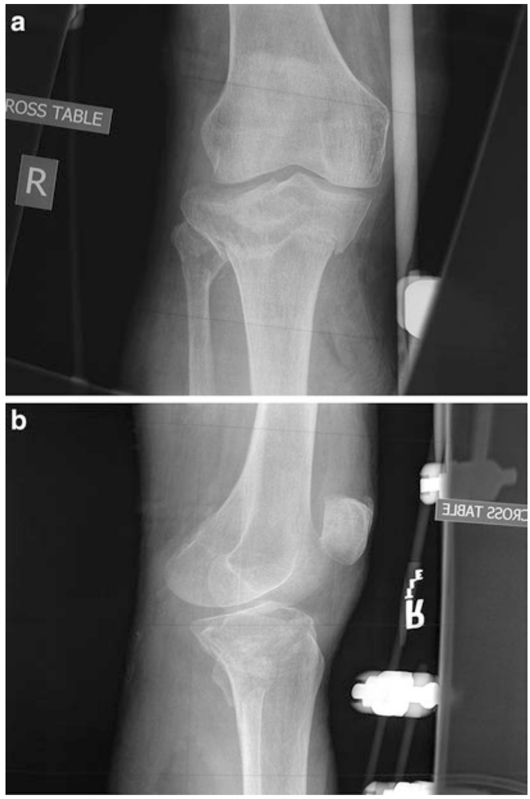

Fig. 21.2 (**a**) AP radiograph knee—postexternal fixation. (**b**) Lateral radiograph knee—postexternal fixation

fracture blisters, and tense swelling are all indicative of the significance of the soft tissue injury. Severe closed soft tissue injuries can take days to weeks to resolve before safe open fracture treatment can occur, and mismanagement of these tissues early, including early attempts at internal fixation, may lead to high rates of wound complications [1–3]. The success of staged treatment protocols for tibial plafond fractures [4] has led to the same philosophy for high-energy tibial plateau fractures [5–7].

Vascular and neurologic injuries are common with high-energy tibial plateau fractures, and a meticulous examination should be performed and documented. Additionally, compartment syndrome can result acutely or after restoration of length [8, 9]. In one series of 67 consecutive patients with bicondylar tibial plateau fractures or fracture-dislocations, compartment syndrome was reported in 27% of patients. The authors note that compartment syndrome was more common after fracture-dislocation, occurring in over half of their patients (9/17) [9]. Similarly, Wahlquist and coworkers reported compartment syndrome in six of nine patients, one anterior tibial artery occlusion, and one peroneal nerve neurapraxia in type C fractures, described as medial tibial plateau fractures that extended lateral to the intercondylar spines [8]. Although optimal timing of fixation and wound closure in patients with tibial plateau fractures with associated compartment syndrome remains unknown, infection risk in these patients is higher [7, 10–12].

Declaration of Specific Diagnosis

AB is a 55-year-old female who presents with a high-energy, bicondylar tibial plateau fracture. Her radiographs demonstrate a depressed lateral

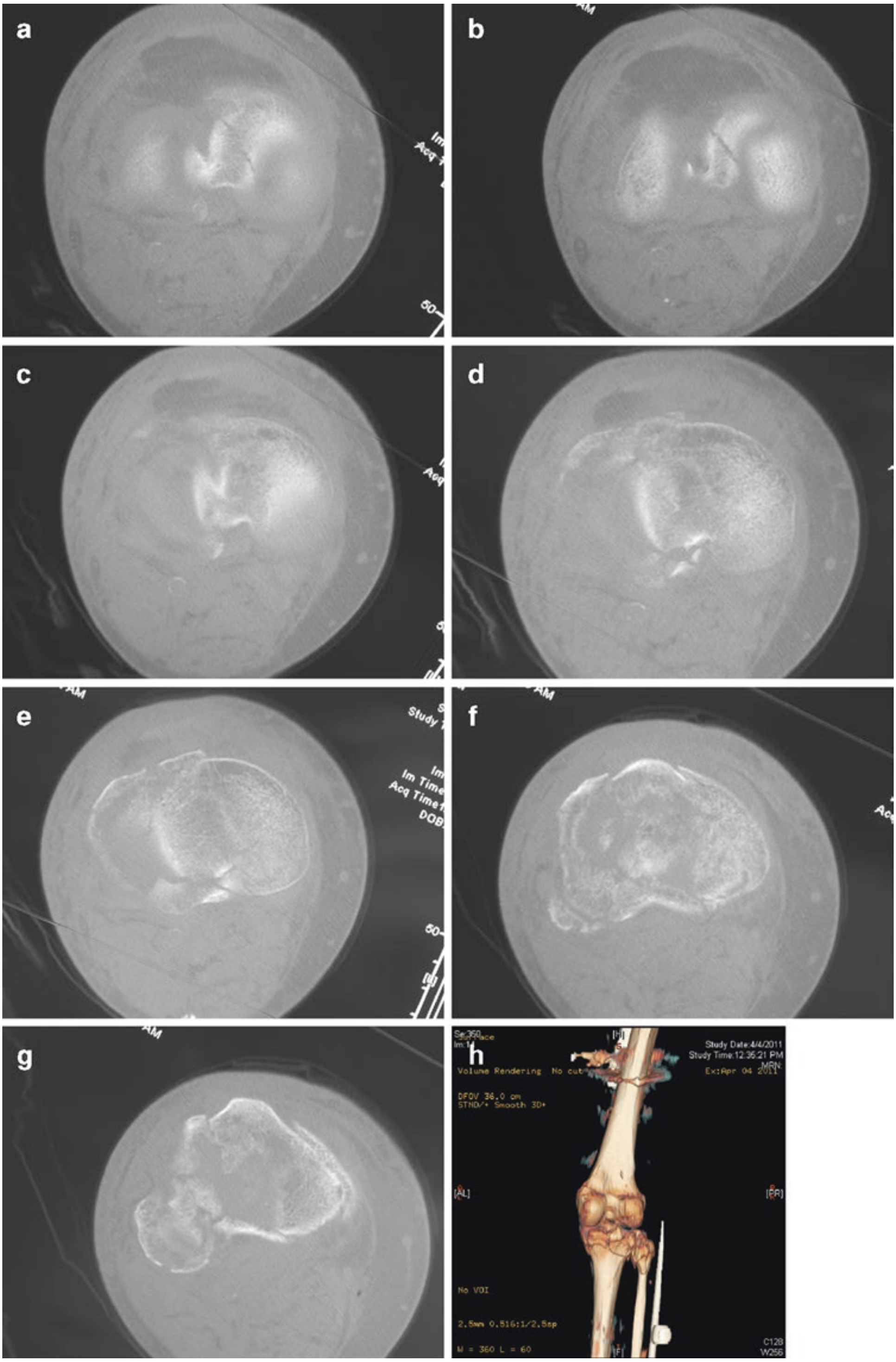

Fig. 21.3 (**a–g**) Axial CT proximal tibia. (**h**) 3 D CT proximal tibia

joint surface, malalignment and shortening of the tibia, and osteopenic bone. In addition, the medial condylar fragment is a short segment.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following:

1. Stabilize the knee while allowing soft tissue swelling to resolve.
2. Restore coronal and sagittal plane alignment of the tibia.
3. Prevent soft tissue complications.
4. Restore smooth joint surface to decrease risk of posttraumatic arthritis.
5. Preserve the lateral meniscus.
6. Regain functional, pain-free knee range of motion.
7. Return to normal life activities.

Treatment options include:

Non-operative treatment:

1. Long Leg Cast Transitioned to a Hinged Knee Brace

Operative treatment:

2. Immediate hybrid external fixation with limited ORIF of the joint surface
3. Staged fixation including temporary spanning external fixation followed by delayed ORIF with one laterally based locked plate
4. Staged fixation including temporary spanning external fixation followed by delayed ORIF with dual plating through two incisions

Evaluation of the Literature

There is an abundance of literature on tibial plateau fractures. Identifying the pertinent information for this patient was achieved by first performing a PubMed search of "bicondylar tibial plateau fractures." This resulted in 135 references; English limits were applied which yielded 125 references. All abstracts were reviewed to ensure general relevance to the fracture type. Articles were then reviewed, and reference lists were utilized for further data or clarification. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

There are multiple treatment options for this patient with a bicondylar tibial plateau fracture. The following discussion reviews the relevant literature to determine the most optimal treatment.

Non-operative Treatment

Non-operative management of tibial plateau fractures can be successful in a well-aligned fracture with a stable knee and has been reported with long-term follow-up. In 1973, Rasmussen published outcomes on 260 patients treated surgically only if clinical examination revealed instability of the extended knee joint, regardless of radiographic appearance of the fracture and joint surface. In 1986, Lansinger and coworkers [13] published 20-year outcomes on 102 of the original Rasmussen patients. Within this final group, there were 18 bicondylar fractures; six were stable and treated non-operatively, two were unstable and treated non-operatively, and ten were unstable and treated surgically. Fifteen of these 18 patients had good to excellent outcomes [13].

DeCoster and coworkers reported a 10-year follow-up data on 29 patients with tibial plateau fractures with age ranging from 30–82 years treated in a cast brace [14]. Nine of their patients had bicondylar fractures, including two that were non-displaced. At a 10-year follow-up, four of these patients had minimal or no radiographic arthritic changes, and five had moderate or severe changes. The authors recommended other forms of treatment for displaced bicondylar fractures.

Mehin and coworkers recently reported non-operative management of 66 patients with a tibial plateau fracture identified in a large database search undertaken to determine the average 10-year incidence of posttraumatic arthritis necessitating reconstructive surgery. The 10-year Kaplan-Meyer survival curve was 23% with three patients undergoing total knee arthroplasty and one patient requiring an alternative reconstructive procedure [15].

Operative Treatment

Acute Internal Fixation

In a recent review of a cohort of 102 fractures treated with internal fixation within 72 h of injuries in bicondylar tibia plateau fractures (43-C), 15.7% of patients had a reoperation to year and 8.8% had a deep infection, although only 25% of these patients had a dual-incision approach. In a recent retrospective cohort study and prospective data collection looking at 102 OTA/AO type 41-C bicondylar tibial plateau fractures fixed within 72 h from injury, 91.3% of the fractures were treated with nonstaged treatment. Of these, 82.3% were treated within 72 h, of which 15.7% (16) required an additional surgical procedure within 12 months. Complications included wound infection requiring surgical management, compartment syndrome requiring fasciotomies, nonunion, early fixation failure, and implant removal for discomfort [16].

One thing to consider when deciding on early definitive fixation is the length of surgery. A review looking at surgical times for THR found that although the incidence of SSI in THR was significantly higher in operations lasting for longer than the T time ($P < 0.05$), no association between risk of SSI and T times set at 1 h, 1.5 h, or 2 h was observed for hip hemiarthroplasties. In conclusion, operations lasting for longer than the T time were associated with a higher risk of SSI in most categories. In the hip prosthesis category, this association only applied to THR [17].

Hybrid External Fixation with Limited Open Treatment of the Joint Surface

Extensile open approaches for treatment of severe tibial plateau fractures have been associated with high complication rates [1]. Following these reports, alternative treatment methods have become popular. One such method is circular or hybrid external fixation, with or without percutaneous lag screw fixation or limited open reduction of the joint. This technique minimizes the surgical soft tissue disruption while allowing restoration and alignment of the metaphyseal segment and early motion [18].

Multiple saw bone studies have shown that hybrid external fixation constructs provide equal stability with similar loads and modes of failure to dual plating [19, 20]. Preliminary clinical studies by Stamer and coworkers [21] and Watson [3] have demonstrated the usefulness of this technique, with good to excellent outcomes in 16 of 23 patients and an average HSS knee score of 82. The Canadian Orthopedic Trauma Society performed a randomized trial comparing standard open reduction internal fixation with medial and lateral nonlocking plates to circular fixator application with percutaneous and/or limited open reduction techniques [22]. At 2 years, there was no difference in knee range of motion, mean HSS knee score, and return to pre-injury activities, although only 21% (14 of 66) of all patients returned to their prior activity level. Complications requiring additional unplanned surgical procedures were significantly higher in the ORIF group, with 18 patients requiring 37 surgeries compared to 15 patients needing 16 procedures in the circular fixator group. Also, the authors reported a 17.5% deep infection rate in the ORIF group compared to 2.3% in the circular fixator group. Two patients randomized to the circular fixator group underwent ORIF because of inability to reduce the intra-articular portion of the fracture.

The longevity of the knee joint after reconstruction of a bicondylar plateau fracture is an important outcome for patients and has been reported. Weigel and Marsh reported minimum 5-year follow-up data on 20 patients who sustained high-energy tibial plateau fractures with severe soft tissue injury, treated with limited ORIF of the joint and monolateral external fixation [23]. They reported good to excellent clinical outcomes in 19 of 22 patients using Iowa knee scores. Despite an average residual articular displacement of >3 mm, they report a relatively low prevalence of grade 2 or 3 arthritic changes (5 of 22). Their patients noted improvements for an average of 2.1 years after injury which did not deteriorate between 5 and 11 years after injury [23].

A retrospective study reported 3-year and 5-year follow-up data on 127 patients (129 fractures) with high-energy intra-articular bicondylar tibial plateau fractures treated with circular external fixators and minimal internal fixation [24]. At 3 years, patient-reported outcomes, according to the Honkonen and Jarvinen criteria [25], of 106 fractures were good to excellent, and at 5 years, these results did not deteriorate among 101 patients. Fifty-three percent of patients were able to participate in recreational activities, including limited running and aerobics. The authors noted poor functional results at 3 years and radiographic arthritic changes at 4 years in patients with radiographic articular step-off greater than 4 mm. There were no excellent or good results in the four patients with varus malalignment greater than 10° [24].

Septic arthritis has been reported with the use of circular external fixator constructs presumably due to intra-articular placement of the periarticular transfixion pins [18]; a safe distance of 14 mm below the subchondral bone has been reported to avoid the reflected joint capsule [26].

Staged Columnar Fixation

Patients with a minimally displaced medial column can be treated with early fixation of the medial column followed by placement of a splint or, if highly unstable, external fixator and then delayed fixation of the lateral tibia plateau. This can decrease the use of external fixators which has been associated with an increase in MRSA infections [27]. Staging the procedures also decreases the duration of each procedure, and duration of procedure greater than 2 h has also been associated with deep infection [16]. With a staged protocol, each procedure may be less than 2 h, but combined medial and lateral approaches for fixation are almost always greater than 2 h. When looking at the complication rates and cost of SCF versus external fixation, a retrospective study found that difference in complication rates was not statistically significant but the average cost in SCF was approximately $2000 less than external fixation and delayed internal fixation ($p < 0.0001$) [28].

Spanning External Fixation and Delayed Open Reduction and Internal Fixation

Severe bicondylar fractures with significant soft tissue injury treated with open reduction and internal fixation through extensile approaches are plagued with complications [1, 2]. Alterations to surgical approaches were introduced to limit additional injury to the soft tissue envelope [29]. With the introduction of locked plating, many felt that bicondylar plateau fractures could be stabilized with a laterally based locked plate; however, early results with these implants proved otherwise with multiple reports of loss of alignment into varus [30–32]. One biomechanical study reported that a lateral locked plate and dual plating offered comparable stability; however, the bicondylar fractures tested did not include a posteromedial fracture fragment and a short medial fracture fragment, nor were they in osteopenic bone [33].

Recent publications from regional referral trauma centers utilizing their respective trauma databases identified the posteromedial fracture fragment in 31–59% of intra-articular bicondylar fractures [34, 35]. These fractures are consistent with the fracture-dislocation pattern originally described by Hohl in 1967. A resurgence of attention to the posteromedial fragment occurred due to varus failures with attempts to avoid the classic buttressing of this fragment [30, 31, 36]. A biomechanical study performed on bicondylar fracture patterns that included a posteromedial fracture fragment supports the need for a buttress plate. The use of a conventional 3.5 mm nonlocking lateral proximal tibial plate and a one-third tubular plate placed posteromedially as a buttress had the highest average load to failure over multiple constructs, including lateral locking plates [37].

Bicondylar fractures with a posteromedial fragment are now more commonly treated with two-incision techniques to allow for adequate antiglide or buttress plating of this fragment, followed by an anterolateral approach to address the typical associated lateral joint injury [38, 39]. Weil and coworkers reported their technique and outcomes with supine positioning for both approaches; they reported no failures into varus and articular reductions to within 2 mm of anatomic in 74% (20/27) of patients [39]. Utilizing the two-incision technique, Eggli and coworkers reported no late collapse into varus, no infections, and average Lysholm knee scores of 83.5 [38].

Barei and coworkers reported functional outcome data using the Musculoskeletal Function Assessment (MFA) in 41 patients at an average of 59 months after treatment of complex intra-articular bicondylar fractures using dual incisions [40]. They reported 55% (17/31) of the articular reductions to be ≤2 mm and 42% (13/31) between 3 mm and 5 mm from anatomic at the joint. Regression analysis associated a better MFA score with a satisfactory articular reduction. Rademakers and coworkers reported an average Neer knee score of 81.5 at a mean follow-up of 14 years (range 5–27 years) for 15 complex intra-articular tibial plateau fractures. Patients with 5° or more malalignment were significantly more likely to develop moderate to severe arthritis than patients with an anatomic knee axis [41].

Two recent studies reported on subsequent total knee arthroplasty after tibial plateau fracture. Mehin and coworkers did a database search and recently reported a 10-year incidence of posttraumatic arthritis requiring reconstructive surgery in a group of 311 patients with tibial plateau fractures. Although the authors included all patterns of fractures in their results, as well as operative and non-operative treatment, they reported 3.5% (nine patients) in the operative group who underwent a reconstructive procedure, with five of those patients getting a total knee arthroplasty. The 10-year Kaplan-Meyer survival analysis for the operative group was 97% [15]. In another database search, Wasserstein and colleagues identified 8426 patients who underwent surgical fixation for a tibial plateau fracture and matched each patient to four people in the general population. The likelihood of undergoing total knee arthroplasty at 10 years in the tibial plateau fracture group was 7.3% compared to 1.8% in the matched controls. After adjusting for comorbidities, tibial plateau ORIF was associated with a greater than fivefold increased risk of total knee arthroplasty, with older age and bicondylar fractures increasing the risk [42].

Operative treatment of tibial plateau fractures is well accepted in young patients, but what about in our 55-year-old patient? Su and colleagues reported on 39 tibial plateau fractures treated operatively in patients 55 years and older. They found 87% (34 of 39) of their patients had a good to excellent clinical outcome according to Rasmussen criteria; however, external fixation was associated with significantly worse Rasmussen radiologic, short MFA, and SF-36 general index scores [43]. Biyani and colleagues reported results of open treatment of tibial plateau fractures in patients with a mean age of 71.7 years, including eight patients with bicondylar fractures. At an average of 3.7-year follow-up, five of those eight patients had good to excellent outcomes [44].

Older patients or patients with osteopenic bone present an additional challenge with management of these complex fractures. Lateral locked plating of bicondylar fractures in osteopenic cadaver bone revealed screw cutout in the medial fragment as the mode of failure [45]. The mean failure loads in two groups of cadaveric tibial plateaus, distinguished by bone mineral density (BMD) as measured by dual-energy X-ray absorptiometry (DXA), were significantly lower in the groups with lower DXA BMDs. Both external fixation and dual plating were sensitive to the bone quality with all failures due to cutout within the bone [46]. Age and poor bone quality are associated with higher failures of fixation in the treatment of tibial plateau fractures [47] and a higher risk for needing subsequent total knee arthroplasty [42]. Some authors are advocating ORIF with dual plates and supplemental external fixation postoperatively to avoid fixation failures in this geriatric patient population [48]. Antiglide plating has demonstrated improved biomechanical stability in osteoporotic bone in other anatomic regions [49]. Also, the addition of locked screws in hybrid plating constructs improves construct fatigue qualities in osteoporotic bone [50].

Table 21.1 Evidentiary table: A summary of the evidence for dual plating for bicondylar tibial plateau fractures

Author (year)	Description	Summary of results	Level of evidence
Barei et al. (2006) [34]	Retrospective chart and radiographic review	41 patients with OTA type 41-C3 fractures treated with dual incisions and dual plating. MFA[a] outcomes at average of 59 months correlate with articular reduction	IV
Canadian Orthopedic Trauma Association (2006) [22]	Multicenter randomized clinical trial	OTA type 41-C1, C2, C3 fractures treated with limited open fixation + circular frame versus dual plate ORIF. Similar fracture reductions and clinical outcomes. Increased complications with ORIF. Persistent residual deficit at 2 years	I
Barei et al. (2004) [29]	Retrospective clinical review	83 patients with OTA type 41-C3 fractures treated with two-incision dual plating. 62% satisfactory articular alignment. 91% satisfactory coronal plane alignment	II
Unno et al. (2017) [16]	Retr ospective cohort study and prosp ective data collection	102 OTA/AO type 41-C bicondylar tibial plateau fractur es fixed. 91.3% of the fractures were treated with nonstaged treatment. Of these, 82.3% were treated within 72 h. 15.7% (16) of these required an additional surgical procedure within 12 months	IV

[a]*MFA* Musculoskeletal Function Assessment

Evidentiary Table and Selection of Treatment Method

The key studies in treating AB are noted in Table 21.1 [16, 22, 29, 34]. Based on the literature, the authors feel that the best treatment in this case would be spanning external fixation, followed by delayed open reduction and internal fixation through two incisions with a posteromedial antiglide plate due to her short medial segment and osteopenic bone, followed by traditional anterolateral plating with a submeniscal arthrotomy to evaluate the joint reduction with preservation, and repair of the lateral meniscus if injured.

Definitive Treatment Plan

The overall goal in managing AB's fracture is to recreate a smooth joint surface, to restore coronal and sagittal plane alignment, to have stable fixation that allows early motion, and to avoid complications. She was initially placed into temporary spanning external fixation until her soft tissue envelope became more amenable to safe definitive internal fixation. After 2 weeks, she returned to the operating theater.

The authors opted to retain the external fixator to assist with maintaining length. The patient is positioned supine with a bump under the contralateral hip so the injured leg would rest in external rotation. After routine preparation of the leg and the external fixator, an incision is made 1 cm posterior to the posterior medial edge of the tibia, at the level of the apex of the posteromedial fracture fragment. The fascia over the medial head of the gastrocnemius-soleus is divided. The pes anserine tendons are retracted anteriorly. The fracture apex is visualized and cleaned of callus. The fragment is reduced and held using bone holding clamps, manipulation of the knee, and Kirschner wires. The reduction is confirmed under fluoroscopic guidance. A posteromedial antiglide plate is utilized.

The bump is then removed from the contralateral hip and placed under the ipsilateral hip so that the knee is in neutral rotation. A vertical anterolateral incision is made lateral to the patellar tendon. The iliotibial band (ITB) is identified and split, taking care to identify the layer between the ITB and the capsule. A submeniscal arthrotomy is performed to allow evaluation of the impacted joint surface. The lateral meniscus is identified, tagged, and preserved. The anterolateral muscle is elevated off the anterolateral tibia to allow submuscular plating. The anterolateral fragment is booked open, and the depressed articular surface is elevated and supported with allograft bone to hold the reduction. The anterolateral fragment is reduced. A lateral underbent plate is placed submuscularly and secured onto the tibia affecting a reduction force and providing a lateral buttress. The reduction of the joint is confirmed by direct visualization using the submeniscal arthrotomy, and restoration of tibial alignment is confirmed using fluoroscopic guidance. If there is any question regarding the alignment, full-length sterile plain radiographs of the tibia are obtained prior to closure.

The meniscus is reduced and the stay sutures are brought through the ITB; then the ITB is closed. Once this closure is secure, the tag sutures to the meniscus are tied from posterior to anterior holding tension on the next suture to affect an inside-out repair. The remainder of the wound is closed in layers. Postoperatively, the patient is maintained in her spanning external fixator to protect the repair secondary to her osteopenic bone. Use of a spanning frame postoperatively is unusual, but it can help prevent early collapse in severe osteopenic fractures. The frame is removed once evidence of bony healing is demonstrated on plain radiographs. Following removal of the external fixator, the patient will begin physical therapy for knee range of motion. She will be maintained protected bearing for up to 12 weeks.

Predicting Outcomes

In general, there are many factors that play a role in assessing the outcome data of tibial plateau fractures. Fracture pattern and type, isolated injury versus multitrauma, and complications all influence outcomes. In general, tibial plateau fractures have a favorable outcome if metaphyseal alignment is maintained and complications are avoided [23]. Preservation of the lateral meniscus is also associated with a lower arthrosis rate and improved long-term outcomes [51]. The importance of the accuracy of the articular reduction [29] compared to a well-aligned knee [41] remains controversial, and both components [24] likely have a role in patient outcomes.

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22 Closed Diaphyseal Tibia Fractures

Michel A. Taylor, Marlis T. Sabo, and David W. Sanders

Case Presentation

AJ: 31-Year-Old Male with Leg Pain

AJ is a 31-year-old male who presents to the emergency department with a chief complaint of right leg pain after being struck in the leg with a 1000 pound piece of granite while at work. He denies any other injuries or pain. On primary survey he is found to have a GCS of 15 and a patent airway and is hemodynamically stable. On secondary survey he is found to have gross deformity to the middle aspect of the right lower leg. He has no past medical history. He takes no medications and has no allergies.

On physical examination, the dorsalis pedis and posterior tibial pulses are palpable and equal to the contralateral extremity. No open wounds are noted. Neurological examination is unremarkable. Right leg compartments are firm but compressible. No pain is elicited with passive stretch of toes, but pain is present with palpation over the area of deformity. No pain or deformity is noted in the ipsilateral thigh, ankle, or foot.

Radiographs of the right leg are demonstrated in Fig. 22.1a, b.

Interpretation of Clinical Presentation

This 31-year-old man has sustained a crush injury to his right leg. There are two broad issues which need to be considered when managing this patient: the bony injury described and shown above and the severe soft tissue injury that may be associated. The x-rays demonstrate a displaced middle 1/3 tibial shaft fracture with shortening, varus angulation, and apex anterior, accompanied by a proximal fibula fracture. Considering the high-energy nature of this crush injury and the location of the fracture, this patient is at high risk of developing a compartment syndrome in the following hours, and careful monitoring including frequent clinical reassessments is critical in the early management of such an injury. This patient has suffered a crush injury, and the soft tissue findings can often take time to fully manifest [1]. The standard of care for diagnosing and monitoring compartment syndrome in an awake and cooperative patient is serial clinical assessments [2] focusing on the patient's pain which may be out of proportion with the apparent injury, analgesic requirements, and physical examination findings such as pain elicited

M. A. Taylor (✉) · D. W. Sanders
Department of Surgery, Victoria Hospital—LHSC, University of Western Ontario, London, ON, Canada
e-mail: michel.taylor@duke.edu

M. T. Sabo
Department of Surgery, South Health Campus, Cumming School of Medicine, Calgary, AB, Canada

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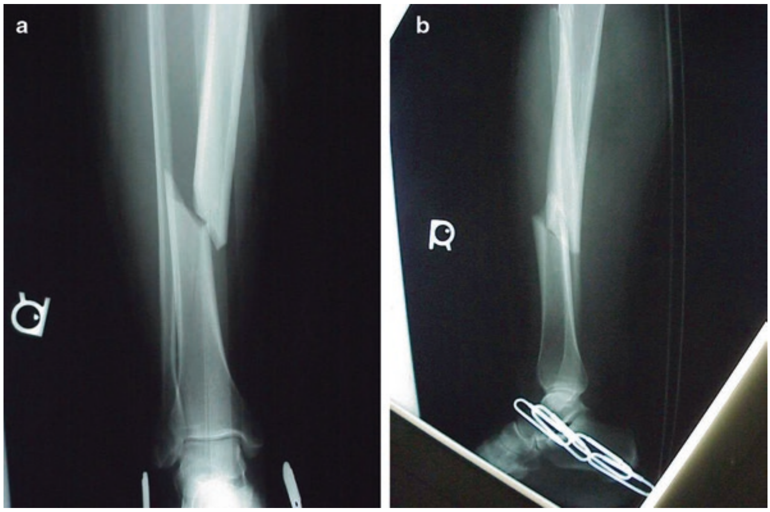

Fig. 22.1 (**a**) AP radiograph right tibia. (**b**) Lateral radiograph right tibia

with passive stretch of the affected compartment. Another possible adjunct to consider would be compartment pressure monitoring [3]. When correctly performed in an alert and reliable patient, direct intracompartmental pressure monitoring devices have been found in one study to be as effective at detecting compartment syndrome and preventing its sequelae as clinical evaluation [2].

In addition to serial monitoring for the development of compartment syndrome, the patient requires a formal review of systems and secondary survey to assess for the presence of any associated injuries. Splinting of the limb in a well-aligned position provides some pain relief, helps to settle the surrounding soft tissues, and facilitates patient movement and transfers. Following splinting, the neurovascular status of the limb should be reassessed, and x-rays should be ordered. The patient should be admitted to the hospital in a step-down or monitored setting for frequent compartment pressure checks, and appropriate medical orders should be provided.

Declaration of Specific Diagnosis

The specific diagnosis is an isolated, closed displaced right tibial shaft fracture with a proximal fibular fracture secondary to a high-energy crush injury.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals:

- Ensure that this is an isolated injury by performing a thorough secondary survey.
- High index of suspicion for, and early diagnosis of, compartment syndrome through serial clinical examinations.
- Expedite closed reduction and stabilization of the fracture.
- Fracture union with acceptable alignment.
- Maintain full range of motion of the knee and ankle.
- Return to baseline function within a reasonable time frame.

Treatment considerations:

1. Does this patient require surgical treatment?
   (a) For fracture reduction and fixation?
   (b) For compartmental decompression via fasciotomy?
2. If surgical treatment is required, which treatment modality is best in this circumstance?
   (a) Intramedullary nail versus external fixation versus plate osteosynthesis
3. Would this patient benefit from adjunctive non-surgical treatments?
   (a) Ex: BMP, LIPUS

Evaluation of the Literature

Search terms used in PubMed included "tibia," "non-operative," "plate osteosynthesis," "external fixation," and "intramedullary." Limits placed were "English," "Human," and "All adult." Search results were reviewed for applicability to closed, acute, mid-, and proximal shaft tibial fractures. References cited by identified studies were scanned to confirm that applicable studies were not overlooked. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Review of Pertinent Articles and Evidence

Non-operative Management

The non-operative management of tibial shaft fractures was the standard of care for generations prior to the advent of safe and reliable internal fixation techniques. It remains a viable treatment option in selected cases. Sarmiento and Latta [4] reported on a case series of 434 patients who were treated with a functional brace and early weight bearing. They suggest that indications for functional bracing include an isolated closed fracture with initial shortening of 12 mm or less and initial angulation of 6° or less after manipulation. An initial long leg cast was placed, which was then converted to a functional brace at a mean of 26 days post fracture. Patients were then permitted weight bearing as tolerated. Nonunion rate was 0.9%, and 97% of patients had residual angulation of 8° or less in the coronal plane, and 93% had angulation of 8° or less in the sagittal plane. They did not comment on time to union and number of clinic visits required for monitoring of the bracing or fully account for the loss to follow-up. In an earlier work assessing outcomes of functional bracing with proximal tibial fractures, displaced fractures had a higher risk of angulation and displacement at final follow-up. However, the subgroup that had normal alignment of the fracture at the start of treatment maintained it [5].

Oni and colleagues [6] reported on a group of 100 patients with closed tibial shaft fractures treated non-operatively. The rate of delayed union (defined as fractures not yet healed by 20 weeks) was 19%, with 4% of patients undergoing subsequent surgery to achieve fracture union. Ninety-seven percent had <10° coronal plane malalignment, 96% had <10° sagittal plane malalignment, and 95% had 1 cm or less shortening. Short-term assessment of ankle stiffness demonstrated that 43% had restriction of movement between 3 and 24 months following the injury. Eighty percent returned to work within 20 weeks of fracture. The authors concluded that there were few indications for surgery in this patient population.

In a subsequent trial comparing cast management with closed intramedullary nailing of unstable tibia fractures, Hooper and colleagues [7] noted that 6 of 33 patients treated in a cast had up to 10° of coronal plane malalignment, while 14 of 33 had up to 2 cm shortening. In the nail group, only two patients experienced shortening up to 2 cm, and no angular malunions were noted.

In a recent multicenter prospective trial, Obremskey and colleagues compared closed reduction and long leg casting vs. reamed IMN for stable tibial shaft fractures. All patients were allowed to weightbear immediately. At 3 months, patients treated with an IMN had better ankle dorsiflexion and plantarflexion, however, this difference was no longer evident at 6 and 12 months. Patients treated with IMN also showed a higher rate of return to work at 3 months, although this difference was not significant at 6 or 12 months. Although there was a trend toward increased union rates at 3 months in the IMN group, this difference was not statistically significant. Three out of 15 fractures treated non-operatively were malaligned at 6 months compared to 1/17 treated with IMN. Malunion occurred in one fracture in the non-operative group and none in the IMN group [8].

With respect to AJ, the evidence by Sarmiento and Latta suggests that he is likely to maintain his length and current alignment with cast or brace treatment, making non-operative management a potential option for him. However, some degree of malalignment appears to be a risk following non-operative management. He currently has a varus deformity at the fracture site which could be improved with reduction. This deformity could be managed with careful cast wedging by a surgeon familiar with the technique. In general, cast wedging in adults is time-consuming and requires close surveillance for loss of correction. The surgical options presented below are more likely to reliably control deformity.

Operative Management

Plate Osteosynthesis

Similar to non-operative management, plate osteosynthesis of closed diaphyseal tibial fractures was more commonly employed in the past. An early case series of 181 tibial fractures (137 diaphyseal) treated with acute plate stabilization yielded a union rate of 95.4%, a total infection rate of 6.6% (severe open injuries were included), delayed wound healing in 1%, and a hardware removal rate of 15% [9]. The author concluded that surgical plate fixation of these fractures offered multiple advantages over the standard non-operative treatments available at the time.

Van der Linden and colleagues compared plate osteosynthesis with non-operative treatment in a group of 100 patients with both closed and open tibia fractures. Unsurprisingly, the time required for the treatment intervention was significantly longer for the plated group compared to the non-operative group. There were nine superficial infections in the plated group (18% versus 2% for non-operative group), four nonunions (8% versus 6%), two deep infections (4% versus 0%), and no re-fractures (0% versus 2%). The length of stay was significantly longer for the operative group, but the median time to healing was shorter (12 weeks versus 17 weeks). Furthermore, fracture malalignment was less likely in the operative group. In the plate fixation group, open fractures had a higher rate of delayed union compared to closed fractures [10].

A retrospective review of 77 patients undergoing plate fixation of a tibial shaft fracture yielded a wound complication rate of 5.2%, a hardware-related complication rate of 9.1%, and a delayed union rate of 2.6%. All of the patients but one were back to full weight bearing by 15 months [11].

A review of the available prospective literature regarding closed tibial shaft fractures found a pooled superficial infection rate of 9% and deep infection rate of 0.4% for patients undergoing plate osteosynthesis, compared with 2.9% for those undergoing intramedullary fixation, and the rate of reoperation was 4.7% [12]. They found a mean time to union of 14.9 weeks for plate fixation compared to 19.5 and 20.2 weeks for unreamed and reamed nails, respectively, with the lowest rate of overall malunion being in the plate fixation groups.

With regard to patient AJ, in light of the presence of a crush injury, the risk of soft tissue complications and infection is likely higher with plate osteosynthesis. Other treatment options are preferred.

External Fixation

While external fixation is another treatment option for tibial shaft fractures, it is not commonly performed for isolated, closed injuries. However, there are a number of authors who support the use of external fixation over intramedullary nailing, in part due to concerns regarding postoperative anterior knee pain and infection. Hay and colleagues reported on a series of 50 consecutive patients (50 fractures), which included both closed (58%) and open fractures, treated with a dynamic external fixator [13]. Union occurred in all fractures; however, 11 patients required a second procedure in order to achieve union. These cases were either high energy and/or open fractures. There were a total of 43 complications, albeit minor. There were 23 pin site infections, 13 fractures with >5° angular malunion, and 3 nonunions which required conversion to intramedullary nail. The fixators were removed at an average of 19 weeks (range, 10–58 weeks). The authors concluded that with careful application, the external fixator represented an effective treatment option, especially for patients required to kneel for occupational reasons.

Dall'Oca and colleagues [14] described 103 displaced tibial fractures treated with unilateral radiolucent external fixators (67 closed fractures). Five patients were lost to follow-up, and 98 were included in the analysis. Eighty-four fractures healed by 21 weeks without any additional procedures. Five of the closed fractures went on to nonunion (7.6%); there was a superficial and deep pin site infection rate of 7.5% and 1.2%, respectively. Emami and colleagues [15] described 68 patients with closed tibial shaft fractures also treated with uniplanar external fixation. They reported a 55.9% pin site infection rate (38 of 68 patients), an average time to union of 22 weeks, and 3 nonunions at 9 months. Furthermore, there was a high rate of subsequent malalignment as well as unplanned reoperations (61/98). From their series, the authors concluded that external fixation was not an appropriate treatment choice for closed tibial shaft fractures. Modern multiplanar external fixators allow fracture reduction, deformity correction, and compression to be adjusted as needed and may permit immediate weight bearing. At present, the evidence related to these devices is restricted to small series and comparatively short-term results. Nonetheless, these techniques may gain further acceptance in the future.

A systematic review by McMahon and colleagues reviewed studies investigating the use of IMN, ORIF, and circular external fixation (CEF) in the management of segmental tibial fractures. Thirteen studies, comprising 366 cases, met the reviewers' criteria and were included. CEF had significantly longer times to fracture union (31 weeks) compared to reamed IMN which had the shortest time to union (20 weeks). CEF had the lowest rate of deep infections (2%; 1/54) compared to IMN which had the highest (3%; 5/162). This series included both open and closed fractures, and the authors note that some studies reported high rates of infection for open fractures treated with IMN. In addition, IMN had the highest rate of concomitant fasciotomy. Only two studies included functional outcomes for CEF, and results were 73% excellent, 20% good, and 7% fair [16].

With the advent of the locking plate, the external plate or "supercutaneous plating technique" has been described. Zhang and associates reported on their experience with 116 tibial fractures (39 shaft fractures) treated with one-stage external fixation using a locking plate. With respect to the tibial shaft fractures, the mean fracture healing time was 20 weeks (12–28). Complications of pin site infections were seen in 8/116 patients although the authors did not specify which group of fractures (proximal, shaft, distal tibia). All patients returned to their previous level of activity, and there were no nonunions, deep infections, or hardware failures [17].

In regard to patient AJ, based upon the current available literature, external fixation is not the ideal treatment option in this case due to the associated morbidity, the high rate of secondary procedures, and the availability of other treatment modalities.

Intramedullary Fixation

Intramedullary fixation for displaced tibial shaft fractures is widely used and in general the preferred mode of treatment [18]. It offers a relatively minimally invasive approach, reduces time to union (Table 22.1), allows earlier return to activities, and reduces the risk of malunion (compared to non-operative treatment) (Table 22.1). The recurring complication, specifically associated with tibial IMN, is anterior knee pain, with reported rates as high as 79%. The severity of which can be variable but can nonetheless create significant difficulties for patients when performing certain daily activities. Early reports suggested that indications for intramedullary fixation included nondisplaced fractures, distal third fractures, and segmental fractures [19]; however, indications have since expanded to include most tibial fractures including displaced fractures. Once an intramedullary nail has been chosen as the procedure of choice for a given situation, important decisions remain to be made regarding patient positioning, nail start point, handling of the extensor mechanism, the need to perform an open or percutaneous assisted approach, whether or not to ream the medullary canal, the size of the nail, the number of proximal and distal screws, and whether to lock the nail statically or dynamically.

Toivanen and associates [20] investigated the effect of transtendinous versus paratendinous approaches on the prevalence of anterior knee

Table 22.1 Evidentiary table: A summary of evidence supporting preferred treatment for closed diaphyseal tibia fractures

Author (year)	Description	Summary of results	Level of evidence
Court-Brown (1990) [35]	Retrospective case series	123 fractures treated with nailing. Time to union of 16 weeks. Time to return to work and full activities of 12.1 and 14.3 weeks, respectively	IV
Bone (1997) [36]	Retrospective case-control for IM nail versus cast	Time to union 18 weeks for nails, 26 weeks for casts. Nonunion 2% with nail, 10% with cast. Better SF-36 score and earlier return to work with nail	IV
Karladani (2000) [37]	Randomized trial of unreamed nails versus cast with minimal fixation	Time to union for nails was 19 weeks and 25 weeks for casting. Full weight bearing at 14 weeks for nail (22 weeks for cast), 4% nonunion for nails (8% for casts)	II
Toivanen (2001) [38]	Retrospective case-control comparing nails with casting	Time to union 12 weeks for nail, 19 weeks for cast. high rate of knee pain for nails (79%), but much higher incidence of delayed union (15%), malunion, (43%) and stiffness of knee and ankle (15%) in cast group. Nail group returned to work 89 days sooner	III
Sprint (2008) [27]	Randomized trial comparing reamed versus unreamed nails	Unreamed nails associated with a higher rate of primary outcomes. Composite outcome measure, with dynamization events being the majority of observed events	I
Courtney (2015) [21]	Retrospective review comparing infrapatellar and suprapatellar tibial nailing	No difference in oxford knee score, improved alignment in sagittal plane, and less fluoroscopic time for suprapatellar nail	IV
Avilucea (2016) [22]	Retrospective review comparing suprapatellar nail vs. infrapatellar nailing techniques at 2 level 1 trauma centers	Significant lower rate of malalignment in the suprapatellar nail group (3.8%) vs. infrapatellar group (28.1%)	IV
Sanders (2016) [23]	Prospective, nonrandomized study of 37 patients with suprapatellar nail for tibia fractures. 1-year minimum follow-up	No patients reported anterior knee pain at 1 year. 35/37 fractures healed at 1 year. Mean Lysholm knee score 82.1, mean SF-36 physical and mental score 40.8 and 46, respectively	IV
Zhang (2015) [17]	Retrospective review describing outcomes of one-stage external fixation using locking plates. No comparison group	Mean time to union 20 weeks, 6.9% pin site infection rate, no nonunion, deep infections, or hardware failure	IV
Donegan (2016) [24]	Retrospective review of tibial IMN measuring the size of the nail and width of the canal to determine optimal nail/canal ratio	Nail/canal ratio between 0.8 and 0.99 had quicker time to union; ratios <0.8 and >0.99 more likely to not be healed at 12 months	IV
McMahon (2016) [16]	Systematic review of studies investigating the management of segmental tibial fractures treated with IMN, ORIF, and CEF	CEF had longer time to union (31 weeks) vs. IMN (20 weeks). CEF had lowest rate of deep infections (2%). CEF outcome 73% rated as excellent and 20% as good	III
Obremskey (2016) [8]	Multicenter, randomized, prospective cohort study comparing reamed IM nailing versus casting	Unreamed nails had better ankle DF and PF and quicker return to work at 3 months	II
Busse (2016) [31]	Multicenter, prospective, randomized blinded trial comparing LIPUS and sham treatment in tibial fractures treated with IMN	No difference in functional outcome or radiographic healing	I

pain. The study was small with only 42 patients, and the nails were left proud in the knee by an average of 4–5 mm. Over 80% of patients reported anterior knee pain postoperatively with approximately 66% of patients noting a significant improvement or resolution of symptoms following nail removal. However, 70% of patients continued to experience pain with kneeling and squatting at last follow-up despite nail removal. There was no statistically significant difference in outcome measures between the two approaches, but there was a trend toward a better functional outcome in the paratendinous group.

Obremskey and associates compared intramedullary nailing and closed treatment. They utilized a medial paratendinous, lateral paratendinous, and transtendinous approach but unfortunately did not report on the outcomes for individual approaches. However, at 2 years, using the Iowa Knee score, they reported that 33% of patients had no knee pain, 60% had mild pain, and 7% (1/15) had severe pain [8].

A study by Courtney and associates retrospectively compared functional outcomes between infrapatellar and suprapatellar nailing for tibial shaft fractures. They found no difference in the Oxford Knee Score between the two groups. Suprapatellar nailing leads to improved radiographic alignment in the sagittal plane and required less intraoperative fluoroscopic time compared to infrapatellar nailing [21]. A recent retrospective study by Avilucea and associates reviewed the records of all the patients who had been treated with an intramedullary nail for a distal third tibia fracture at two level 1 trauma centers during a 6-year period. They compared the suprapatellar nailing approach (132 patients) with infrapatellar (tendon splitting, medial or lateral parapatellar) approaches (134 patients). They found a significant difference in the rate of malalignment between the two techniques. The infrapatellar group had a malalignment rate of 26.1% compared to 3.8% in the suprapatellar group. The average coronal and sagittal plane alignment was 3.2° ± 1.05° valgus and 2.9° ± 0.9° recurvatum in the suprapatellar group compared to 5.7° ± 1.8° valgus and 5.5° ± 2.3° recurvatum in the infrapatellar group [22].

A prospective nonrandomized study by Sanders and associates looked at clinical and radiographic results of 37 fractures (open and closed) that underwent suprapatellar reamed tibial nailing. Seven fractures were proximal third, 16 were middle third, and 14 were distal third fractures. Thirty-five of thirty-seven fractures were healed at 1 year, there was one malunion (2.7%), and mean ROM arc was 124.4° for the operative leg compared to 127.2° for the uninjured contralateral leg. Most importantly, no patients reported postoperative anterior knee pain at 1 year. Fifteen patients underwent pre- and postnailing knee arthroscopy. Two were found to have grade 2 chondromalacia of the trochlea immediately following nail insertion. However, both patients had normal clinical and MRI results at 1 year [23].

With regard to nail diameter, a recent study by Donegan and associates retrospectively reviewed 78 tibial shaft fractures that underwent intramedullary nailing. Proximal third (18%), middle third (28%), and distal third (54%) were included. By measuring the size of the nail inserted and the width of the canal, as well as the radiographic union scale for tibial fractures (RUST) to calculate a fracture healing score, they determined the optimal nail/canal ratio to prevent nonunion at 12 months. Early time to union was seen in nail to canal ratios of 0.8–0.99, and fractures with ratios less than 0.8 or greater than 0.99 were 4.4 times more likely to not be healed by 12 months [24].

The decision to perform a reamed versus unreamed intramedullary tibial nail has also been a source of debate and controversy. Some studies have found reamed nails to be associated with a reduced risk of screw failure and improved union rates, but this has not been the case in all studies. Blachut and associates compared reamed and unreamed nails and found a trend toward higher nonunion rates in the unreamed group and concluded that there were very few advantages of using unreamed nails [25]. Bhandari and associates performed a meta-analysis comparing reamed and unreamed nails in which they found that reamed nails were associated with reduced nonunion rates (RR = 0.33) [26]. A large randomized controlled trial compared reamed and unreamed tibial nailing techniques [27]. In this landmark study, a total of 826 closed tibial fractures were included. Reamed nails were associated with fewer reoperations, fewer postoperative fasciotomies for compartment syndrome, and fewer subsequent auto-dynamization events. An overall reoperation rate of 13.7% within 12 months was observed.

Whether to lock the nail statically or dynamically has not been decisively clarified in the literature. Early series included various modes of locking, ranging from no distal locking screws to two statically locked screws (Table 22.1). Furthermore, the time at which weight bearing was allowed varied among the different studies, which would certainly have an impact on the outcome. A retrospective study by Drosos and associates found that the choice of locking mode did not influence the time to union if the fracture gap was less than 3 mm. However, dynamically locked nails with a gap greater than 3 mm had a shorter time to union than statically locked nails [28]. The use of multiple locking screws may permit earlier weight bearing, especially in comminuted fractures [29].

Healing Adjuncts

Several surgical adjuncts to help stimulate bone healing have gained popularity over the last several years, including low-intensity pulsed ultrasound (LIPUS) and various bone morphogenetic proteins (BMPs). A blinded randomized trial comparing the effect of LIPUS versus sham ultrasound in tibial fractures treated with reamed, statically locked nails failed to demonstrate a difference in callous formation or healing time [30]. A recent multicenter, prospective randomized blinded study by Busse and associates compared LIPUS to sham treatment in 501 tibia fractures (77% closed) treated with an IMN. Exclusion criteria included tibial shaft fractures with intra-articular extension requiring reduction, bilateral fractures, segmental fractures, and tibial fractures with less than 25% cortical contact and greater than 1 cm gap following surgical fixation. They found no difference when comparing LIPUS to sham with respect to either functional outcome or radiographic healing [31]. A study by Schofer and associates comparing LIPUS with sham treatment in delayed unions (>4 months) found an improvement in mean bone mineral density and a mean reduction in bone gap area for the LIPUS treatment group [32]. Bone morphogenetic proteins (BMP-2) are FDA approved only for the treatment of acute open tibial shaft fractures treated with IMN. The use of BMP (e.g., BMP-2, BMP-7) as a treatment adjunct has also been studied in the treatment of delayed unions and nonunions [33, 34], but there is currently no evidence to recommend their use in acute, closed tibia fractures. With regard to patient AJ, as this is both a closed and acute fracture, there is currently no role for the use of any medical adjuncts.

Limitations of the Literature

With regard to the management of closed tibial shaft fractures, there are several areas in which the literature is lacking. First is in a dearth of well-designed clinical trials. The comparative evidence between the use of tibial nail and other treatment modalities rests almost entirely on small series with significant methodological flaws. Meanwhile, our understanding of intramedullary nail technology and how best to utilize it has evolved considerably. Early series used a variety of different implants and made variable use of locking screws. Moreover, reaming methods or even the decision to ream prior to nail insertion varied significantly. Given the success of current treatment techniques, namely, intramedullary nailing, it is unlikely that large-scale randomized trials will be undertaken comparing tibial nailing to other treatment modalities for closed tibial shaft fractures. There is, however, room in the literature to expand on our knowledge of nailing technique, including nail configuration, material and diameter, start point, patient positioning, use of intraoperative fluoroscopy, postoperative weight bearing, and the use of medical adjuncts.

Barring any complications such as the development of a compartment syndrome, and in the absence of certain important patient factors such as smoking, it is likely that this fracture would heal with either closed reduction and cast treatment or intramedullary nailing. Certain patient- or physician-specific factors, such as physician experience with casting or cast brace management or lack of experience with a specific nailing system or the presence of skilled orthopedic casting technicians and patient occupation (e.g., one that would require kneeling) would make closed reduction and cast treatment a more attractive treatment option compared to intramedullary nail fixation. In this case, given the simple fracture pattern, the mild degree of angulation, and minimal shortening, and given the dearth of high-quality clinical studies proving the superiority of intramedullary fixation over non-operative management, clinical equipoise and judgment play a significant role in the decision-making process. That being said, most surgeons, when considering this case, would likely opt for operative management consisting of intramedullary nailing.

Evidentiary Table and Selection of Treatment Method

Based on the available evidence, the preferred method of treatment for patient AJ would be a reamed intramedullary tibial nail ensuring a safe start point, choosing an appropriately sized nail, and performing an anatomic reduction prior to reaming and nail insertion. As discussed previously, closed reduction and casting, as definitive treatments, risk fracture malalignment and postoperative knee stiffness. The use of plate osteosynthesis is associated with a higher rate of infection and wound complications, and the use of an external fixator is associated with superficial pin site complications and nonunions and lacks evidence to substantiate its use in this case. Therefore, based on the current evidence, in the case of patient AJ, surgical treatment with an IM nail would allow for earlier weight bearing, a faster return to baseline function while restoring anatomical alignment and leading to fracture healing between 12 and 20 weeks. Preoperative discussions with AJ should also include the risks associated with this treatment option, which would include postoperative knee pain, difficulty with kneeling and squatting, nonunion requiring a secondary procedure, and hardware prominence requiring removal (Table 22.1 [8, 16, 17, 21–24, 27, 31, 35–38]).

Definitive Treatment Plan

The goals of treatment of intramedullary tibial nailing are obtaining stable fixation of an anatomically reduced fracture, permitting early or immediate weight bearing as well as the early return to baseline function, and timely union at the fracture site. With regard to operative plan and technique, antibiotics should be administered within 30 min of surgical incisions. The patient is positioned supine on a radiolucent table with a bump under the ipsilateral hip. Tourniquet should be applied and inflated as needed. Although there have been reports of thermal injury following intramedullary reaming with an inflated tourniquet [39], the surgeon should have the option to inflate the tourniquet if an open approach is needed or if significant bleeding is encountered.

In the case of infrapatellar nailing, a minimedial parapatellar arthrotomy can be made before or after the guide wire has been placed in the proximal tibia using fluoroscopic guidance. The ideal nail entry point is at the medial aspect of the lateral tibial spine on the AP radiograph and at the apex of the anterior crest of the tibial plateau on the lateral radiograph [40]. Tornetta and associates described the safe zone for nail placement as being located 9.1 mm ± 5 mm lateral to the midline of the plateau and 3 mm lateral to the center of the tibial tubercle [41]. Using a soft tissue protecting sleeve angled in such way to protect the patellar tendon, the large diameter (ex: 11 mm) entry reamer is used to breach the proximal tibia.

For the suprapatellar nailing approach, the patient is positioned supine, and the operative leg is flexed to approximately 20°. Specific suprapatellar equipment is needed which includes an extension for the targeting device and modified soft tissue sleeves. A 2 cm longitudinal incision is made approximately 1–2 cm above the superior border of the patella. The quadriceps tendon is split in line with its fibers. The soft tissue sleeve is advanced under the patellar tendon and onto the tibial plateau. This step can be challenging, especially if the patient lacks patellar mobility. Once the ideal start point is found, the guide wire is advanced into the proximal tibia. The operator must ensure that the soft tissue sleeve is against the tibial plateau while reaming in order to avoid iatrogenic bony or soft tissue injuries to the knee.

Reduction is performed by applying varying amounts of in- line traction with internal or external rotation of the lower leg. Positioning packs or sheets can be strategically placed under the leg to aid in the reduction. Under fluoroscopic guidance, a reduction tool can then be advanced in the proximal segment in order to assist with the reduction. While an assistant holds the reduction and under fluoroscopic guidance, a ball-tipped guide wire is advanced through the proximal segment of the tibia and across the fracture site, down to the physeal scar at the ankle. Appropriate nail length is then determined, and reaming over the ball tip guide wire can begin. Sequential reaming in 0.5–1 mm increments is performed until light chatter is present at the level of the diaphysis. Nail diameter should be selected based on preoperative templating and intraoperative chatter and should ideally accommodate 5.0 mm locking screws which, biomechanically, are significantly stronger compared to smaller (4.0 mm) screws. Two locking screws should be inserted proximally and two distally. All incisions should be irrigated thoroughly and closed in layers. Appropriate soft dressings should be applied over the incision sites. A postoperative splint is not required for this fracture pattern. The patient should be admitted to the hospital, and compartment checks should continue postoperatively. Immediate full weight bearing is permitted, especially when two distal locking screws have been inserted [29]. Assisted devices (walker and/or crutches) are weaned as tolerated.

Predicting Outcomes

Assuming that AJ is a nonsmoker and does not develop a compartment syndrome or another major complication, the evidence would suggest that he has over a 96% chance of healing this fracture between 12 and 20 weeks with acceptable alignment. His risk of developing at least moderate postoperative anterior knee pain may be as high as 73% but may be lower with newer suprapatellar techniques. He also has approximately a 33% risk of developing symptoms secondary to venous insufficiency and a 35% risk of developing subsequent radiographic evidence of osteoarthritis at the knee and/or ankle, which are similar to the rates seen in the general population [42]. Patient AJ should expect to return to his daily activities and occupation between 12 and 14 weeks, depending on his pre-injury functional, occupational, and recreational status.

In summary, there are a variety of effective treatment options for the management of closed tibial shaft fractures. Each modality has its own specific advantages and pitfalls: namely, an increased risk of malunion in the case of nonoperative treatment, increased infections and wound complications with plate osteosynthesis, local superficial pin site infections and nonunions associated with external fixation, and persistent anterior knee pain with intramedullary nailing. In every situation, individual fracture pattern, location, and associated injuries as well as patient- and surgeon-specific factors must be considered when deciding on treatment, but intramedullary nailing of closed tibial shaft fractures often represents the best and most effective treatment.

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Open Diaphyseal Tibia Fractures

23

Scott P. Ryan, Christina L. Boulton, and Robert V. O'Toole

MI: A 24-Year-Old Male with Leg Pain

Case Presentation

MI is a 24-year-old male who presents to the emergency department with a chief complaint of left leg pain after being thrown off of his ATV while riding in the woods. He denies any other injuries or pain. On primary survey he demonstrates a GCS of 15 and a patent airway and is hemodynamically stable. On secondary survey he demonstrates a gross deformity to the left leg with a large open wound and exposed bone. His past medical history is consistent with depression. He takes no medications, and he has no allergies.

Upon physical examination, the dorsalis pedis and posterior tibialis pulses are palpable and equal to the contralateral extremity. On the anteromedial aspect of the patient's left leg, there is a 12 × 5 cm wound with gross contamination of grass and mud, with exposed bone evident. Sensation to light touch is intact in all dermatomal distributions. The left leg compartments are soft and compressible. No pain is elicited with passive stretch of the toes. No pain or deformity is noted in the thigh, the ankle, or the foot.

Radiographs of the left leg are demonstrated in Fig. 23.1a–c.

Interpretation of Clinical Presentation

This patient is an otherwise healthy young male with an isolated but severe left open tibia fracture. The history of a high-energy mechanism should always trigger a full trauma evaluation to rule out associated and potentially life-threatening injuries. Based on the clinical history and physical examination, the patient is in stable condition without evidence for injury to other organ systems. The severity of bony injury raises concern for concomitant neurovascular injury or compartment syndrome, neither of which appears to be present in this case. The most significant component of our patient's injury is the presence

S. P. Ryan (✉)
Department of Orthopaedics, Tufts University School of Medicine, Tufts Medical Center, Boston, MA, USA
e-mail: Sryan3@tuftsmedicalcenter.org

C. L. Boulton
Department of Orthopedic Surgery, University of Arizona–Banner University Medical Center, Tucson, AZ, USA

R. V. O'Toole
R. Adams Cowley Shock Trauma Center, University of Maryland School of Medicine Department of Orthopedics, Baltimore, MD, USA

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Fig. 23.1 (**a, b**) AP radiograph of the tibia. (**c**) Lateral radiograph of the tibia

of a large (12 × 5 cm) soft tissue defect with exposed bone and gross contamination.

Emergency department care of this injury should include initiation of appropriate IV antibiotic prophylaxis and confirmation or update of tetanus vaccination. Wound care should be expedited and involve the removal of gross contamination and placement of a moist sterile dressing over open wounds. The fracture should be reduced and the extremity placed in a well-padded long leg splint. In cases with severe soft tissue loss or vascular compromise, a decision regarding limb salvage may need to be made at this stage, as well as planning of initial operative irrigation and debridement.

Declaration of Specific Diagnosis

MI is a 24-year-old male with an isolated, high-energy, open Type IIIB segmental tibial shaft fracture with gross contamination of his wounds.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals:

1. Minimization of infection risk
2. Wound management and coverage of soft tissue defect
3. Stabilization and healing of the tibia fracture
4. Mobilization of the patient
5. Maintenance of ankle and knee range of motion
6. Return to normal life activities

In addition to administration of IV antibiotics and surgical debridement of the open wound in a timely fashion, fracture stabilization options include:

1. Conservative/nonoperative treatment—casting/splint
2. External fixation—uniplanar versus multiplanar (ring)
3. Intramedullary nail—reamed versus unreamed
4. Plate osteosynthesis

Evaluation of the Literature

Online searches of the NCBI PubMed database were performed using several relevant keyword combinations. The only filters applied were English Language and Publication Date range: 1/1/1975–5/1/2011. The search words are listed followed by the total number of abstracts generated for each search: "open tibia fracture" (927), "open fracture antibiotic" (423), "tibial external fixation" (898), "tibia plate osteosynthesis" (99), "tibia open reduction internal fixation" (229), "tibia intramedullary nail" (632), "antibiotic beads open fracture" (33), and "tibia flap coverage" (130). A total of approximately 700 abstracts were reviewed in detail, and a review of the full publication and cited references was performed for 86 papers. An additional literature search for chapter revision in 2017 was performed in the same manner with the only filters applied English Language and Publication Date: last 5 years. The search words are listed followed by the total number of new abstracts generated for each search: "open tibia fracture" (20), "open fracture antibiotic" (154), "tibial external fixation" (191), "tibia plate osteosynthesis" (60), "tibia open reduction internal fixation" (14), "tibia intramedullary nail" (137), "antibiotic beads open fracture" (5), "open fracture" (380) and "tibia flap coverage" (130), "Ilizarov open tibia fracture" (51), and "ring fixator open tibia" (4). A total of approximately 250 abstracts were reviewed in detail, and a review of the full publication and cited references was performed for 52 papers.

Antibiotics

Systemic Antibiotics

Multiple high-quality studies exist demonstrating that antibiotics reduce the incidence of infection in open fractures. In 1974 Patzakis' classic article reported the results of a prospective, randomized controlled trial comparing antibiotic treatment regimens for open fractures. A total of 310 patients were distributed into three treatment groups: first-generation cephalosporin (cephalothin), penicillin plus streptomycin, and placebo. A significantly lower infection rate was observed in the cephalosporin group (2.3%, $p < 0.05$) compared to placebo (13.9%) but no significant difference between the placebo and penicillin/streptomycin group (9.7%). The latter of these two findings was felt to be due to a high rate of penicillin and streptomycin resistance among contaminant bacterial strains, but also may be related to the study's inability to detect a difference of this magnitude based on sample size [1].

A Cochrane review in 2004 performed a meta-analysis of eight randomized studies, including the Patzakis article cited above, and concluded that the data "support the effectiveness of antibiotics active against gram-positive organisms in reducing the incidence of early infection in open limb fractures" (risk ratio 0.43, 95% confidence interval 0.29–0.65).

Based on the strength of the evidence, the authors advised that future placebo-controlled trials were "unwarranted" [2]. A more recent meta-analysis of randomized controlled trials confirmed that patients receiving antibiotics were less likely to develop an infection (relative risk ratio of 0.37) [3].

Although there are strong evidence and clinical consensus that antibiotics should be used in the initial treatment of open fractures, there are surprisingly little evidence and consensus regarding what type of antibiotics should be used, and essentially no level I data on this topic. Cephalosporins are typically used for all open fractures, but Gustilo and colleagues first advocated for the addition of an aminoglycoside for Type III open fractures based on the high rate of traumatic wound cultures that were positive for gram-negative organisms (77%) [4]. This recommendation has been propagated throughout the literature, but no randomized controlled trials exist to support it. One study often quoted in support of the routine addition of aminoglycosides was published by Patzakis and colleagues in 1983. The authors report a decrease in open fracture infection rate (14% down to 4.5%) with the routine use of an aminoglycoside plus a cephalosporin for open fractures. However, this study is not randomized or controlled, and several confounding variables exist that could also explain their observed change in infection rate over time [5]. Further, aminoglycosides can be associated with oto- and nephrotoxicity; therefore, concern exists regarding the safety of routine use in open fractures particularly in patients who are not yet well resuscitated and may be at particular risk. Surprisingly little data exist, but at least Pannell and coworkers were able to show no significant difference in the rate of acute kidney injury when gentamicin was used for open fracture in patients with normal baseline renal function suggesting no obvious risk with the use of aminoglycosides [6].

Recently, Redfern and colleagues evaluated the use of piperacillin/tazobactam instead of cefazolin plus gentamicin in Type III open fractures. The study was retrospective and nonrandomized, but the distribution of open fracture types was similar between the two groups. They reported no difference in infection rate; however, they acknowledged that the study was underpowered with only 72 patients included in the final analysis. The authors concluded that piperacillin/tazobactam is an acceptable alternative to cefazolin with gentamicin [7].

Modern surgical site infections have higher rates of MRSA (methicillin-resistant *Staph aureus*) prompting concern with first-generation cephalosporin that do not have good MRSA efficacy. Some clinicians are considering adding MRSA coverage in prophylaxis in open fractures. Saveli and colleagues performed a prospective, randomized pilot trial looking at infection rates in patients receiving cefazolin alone versus cefazolin plus vancomycin. The study showed no difference in infection rate but was significantly underpowered with only 130 patients [8]. Rodriguez and coworkers reported no increase in overall infection rate or the rate of infection with resistant organisms with open fracture antibiotic protocol change to remove routine use vancomycin and gentamicin. The new protocol recommended cefazolin (clindamycin if PCN allergic) for Type I and II injuries and ceftriaxone (clindamycin + aztreonam if PCN allergic) for Type III, but again was limited with only 174 patients [9].

The importance of the timing of the initial antibiotic dose has also been debated. Recently, Lack and coworkers evaluated whether early administration of antibiotics, within 1 h of injury, lowered infection rate. In their retrospective review of Type III open tibia fractures, they found that 95% of patients received the first dose of antibiotics within 3 h from injury. Regression analysis attempted to control for the selection bias and revealed that antibiotic administration greater than 1 h (66 min) from injury and wound coverage greater than 5 days were independent predictors of infection. Those who both received antibiotics within 1 h and coverage within 5 days had the lowest infection rate (2.8%) [10]. Collinge and coworkers reported that performance improvement programs that include education of the emergency and pharmacy departments on the importance of early antibiotic administration significantly decrease the time to first dose in patients with open fractures [11]. The authors agree with these findings and firmly believe that a multidisciplinary approach to treatment of patients with open fractures is necessary for optimal outcome.

The most appropriate duration of antibiotics is also not well supported in the literature. Early recommendations from the 1990s called for wide-spectrum antibiotic therapy for 3 days for Type I and II fractures and 5 days for Type III fractures with additional 72 h of antibiotic treatment following additional operative procedures [12]. In a systematic review of randomized controlled trials, Chang and coworkers reported no difference in infection rate with a longer duration of antibiotics (1 vs. 3–5 days) in pooled data from over 1100 patients [3]. However, no strong evidence exists to guide duration of antibiotic treatment for open fractures. Our current practice, and the recommendation of multiple other authors, is to continue IV antibiotic coverage for 24–48 h after each debridement until definitive soft tissue closure or coverage, but this is based more on preference than backing in the literature.

Our current recommendation is that antibiotic treatment for all open fractures should include gram-positive coverage in the form of a first-generation cephalosporin, fluoroquinolone, or clindamycin (in the penicillin-allergic patient). Antibiotic agents that provide good gram-positive and gram-negative coverage such as piperacillin/tazobactam (Zosyn®), third-generation cephalosporins (e.g., ceftriaxone, cefotaxime), or aminoglycosides (e.g., gentamicin, tobramycin) are also recommended by many authors for use in Type III open fractures. However, while the addition of gram-negative coverage is common at many centers, it is not rigorously supported in the literature. In fact, the Cochrane review [2] and consensus guidelines from the military and endorsed by both the Infectious Disease Society of America (IDSA) and the Surgical Infection Society (SIS) support only a first-generation cephalosporin for all open extremity fractures [13].

Local Antibiotics

Local antibiotic delivery offers the theoretical advantage of increasing the local concentration of antibiotics while minimizing the risk for systemic toxicity. In an animal open fracture model, combination therapy with systemic and local antibiotics has been shown to produce a significant decrease in bacteria count versus systemic therapy alone [14]. In a nonrandomized study, Ostermann and colleagues retrospectively compared 240 open fractures treated with IV antibiotics alone to 845 treated with both IV antibiotics and local PMMA beads impregnated with tobramycin [15]. There was a statistically significant decrease in overall infection rate in the antibiotic bead group (3.7% vs. 12%, $p < 0.001$). There were also significant differences in both the acute infection and osteomyelitis rates for Type IIIB fractures.

In a meta-analysis, Craig and colleagues found that the addition of local antibiotics lowered infection rates in all open fractures; however, no trials directly compared treatment with and without local antibiotics [16]. More recently Lawing and colleagues performed a retrospective cohort study comparing infection rates in open fractures treated with systemic antibiotics with and without administration of a local aminoglycoside. After controlling for confounding variables, such as type of open fracture, the addition of local antibiotics was found to be an independent predictor of lower infection rates [17].

Of note, the use of a negative-pressure wound dressing instead of bead pouch has been shown to decrease the ability of local antibiotics to decrease wound bacterial count in animals [18]. It is not clear if this effect also occurs in humans.

At our institutions, we routinely use antibiotic bead pouches (occlusive watertight dressing over antibiotic beads) and/or an antibiotic-impregnated spacer in highly contaminated wounds or wounds with severe open injuries that require multiple debridements in an attempt to reduce infection and limit exposure of the wound to the nosocomial bacteria within the hospital. The beads or spacer typically consist of polymethyl methacrylate cement mixed with 1–4 grams of vancomycin and 1.2 grams of tobramycin powder per cement pouch.

Operative Irrigation and Debridement

Predebridement Cultures

Some have advocated for the use of predebridement wound cultures to tailor antibiotic treatment for open fractures; however, evidence to support this practice is scant. In a prospective evaluation of 158 open fractures, Gustilo and Anderson reported positive cultures in 70.3% of traumatic wounds but a subsequent infection rate of only 2.5% [19]. In a randomized multicenter double-blind trial conducted in France between 1990 and 1994 comparing antibiotic regimens in the treatment of Type I and II open leg fractures, positive cultures were correlated with the occurrence of infection but were not predictive of the infecting species, which were nosocomial bacteria in most cases [12]. Based on the literature, predebridement cultures are not indicated, and the published data do not support their routine use.

More recently one group has proposed using the results of wound cultures to determine the appropriate timing for wound closure, but this practice is certainly not widespread to date [20] as discussed below in the section on wound closure.

Timing of Initial Debridement

Much debate and little high-quality research exist as to the ideal timing of initial operative debridement of open fractures. At one time it was accepted dogma that open fractures should undergo surgical irrigation and debridement within 6 h of injury to reduce subsequent infection rates. This long-standing idea likely dates back to guinea pig experiments of abdominal wounds from the 1800s, when antibiotics did not yet exist [21].

In a prospective evaluation of 315 patients with severe high-energy lower extremity injuries from the LEAP study, Pollak and colleagues found no significant differences between patients who developed an infection and those who did not with respect to the time from injury to the first debridement, time from admission to the first debridement, or time to soft tissue coverage. Only the time of arrival to the definitive treatment center was correlated with infection, and the authors hypothesized that this might be a marker for the time to adequate resuscitation, although it might also be hypothesized to be related to the timing of antibiotic administration [22]. Clinical issues that appropriately delay the operative treatment include the need for resuscitation, transfer from a center unable to handle the injury, severe head injury, and treatment of other life-threatening chest or abdominal injuries. Operative treatment is now less commonly performed at night due to multiple factors including the emergence of trauma rooms during the day, the theoretical risk of compromised care and decision-making by fatigued or inexperienced surgeons and staff, and the concern that too early of a debridement may underestimate the amount of dead soft tissue in wounds that are closed primarily.

The evolving change in thinking has been borne out in clinical practice. In an examination of practice trends through the National Trauma Data Bank, Namdari and colleagues found that 42% of patients with open tibia fractures underwent initial irrigation and debridement more than 6 h after presentation to the emergency room and 24% of patients were debrided more than 24 h after presentation [23].

Flaws with early studies reporting no difference in infection rate between early and late debridement included differing definitions of "early" and "late" as well as selection bias such as differing number of Type III open fractures in each group. More recently Schenker and coworkers reported a meta-analysis that combined the raw data from these earlier studies and found that earlier time to debridement, defined by either 5 h, 6 h, 8 h, or 12 h, did not decrease the infection rate. This held true when evaluating various open fracture types [24].

In addition, in a multicenter, prospective cohort study of over 700 open fractures of upper and lower extremities, multivariate regression analysis failed to show that time to debridement was associated with infection. The only variable that was associated with infection was increasing open fracture type as would be expected [25].

Our current recommendation based on the available literature is that surgical irrigation and debridement of typical open tibia fractures can be safely performed within the first 24 h after injury and is best performed when the patient is appropriately resuscitated and medically optimized for surgery. Due to the paucity of data, the safety of delaying debridement more than 24 h remains unclear. In our clinical practice, we favor more urgent debridement of open fractures that are grossly contaminated or associated with farm injuries, such as the one in our case study; however, this is personal preference and certainly not supported by the literature.

Irrigation

Several studies have compared irrigation solutions, methods, or volumes for use in open fracture treatment. Anglen reported the results of a large prospective randomized comparison of bacitracin solution and nonsterile castile soap solution for the irrigation of open fractures of the lower extremity. Analysis of outcomes showed no difference in rates of infection (18% vs. 13%) or delayed union (25% vs. 23%). The bacitracin group did have a significantly higher rate of wound complication (9.5% vs. 4%, $p = 0.03$), leading the author to advise against its use [26].

Most recently the FLOW (fluid lavage of open wounds) investigators completed an impressive international, blinded, randomized controlled trial at 41 sites evaluating the pressure of irrigation as well as the type of irrigation used in treatment of 2447 open fractures. The primary outcome measure was reoperation for either infection, wound problem, or nonunion. There was no difference in the reoperation rate when comparing high versus low versus very low pressure. However, there was a statistically significant higher reoperation rate in patients randomized to soap irrigation compared to saline (14.8% vs. 11.6%; $p = 0.01$). The authors concluded that very low-pressure irrigation is a low-cost alternative to high-pressure irrigation systems, and saline should be used as the routine irrigation fluid in open fractures [27].

Irrigation volume is thought by some to be another important factor; increased volume may improve wound cleansing, but the optimal volume is unknown. The historic recommendation has been for 3 L of irrigant for Gustilo Type I fractures, 6 L for Type II fractures, and 9 L for Type III fractures. However, this is not supported by rigorous research; rather it is a convenient volume given the widespread availability of 3 L saline bags [28].

The authors routinely use 3–9 L of saline irrigation via very low-pressure cystoscopy tubing or low-pressure pulsatile lavage during irrigation and debridement of open fractures.

Debridement

A thorough debridement of all devitalized and contaminated tissue is universally recommended in the treatment of open fractures and is often cited as the "key" step in reducing postoperative infection after open fracture, but to our knowledge, there is almost no support in the literature of this claim. Further, little guidance is available on how much bone should be maintained or the correlation between extent of bony debridement and subsequent rates of nonunion or infection. The high rate of chronic osteomyelitis (10–25%) seen in open tibia fractures is thought to be partially due to incomplete initial debridement of devitalized bone [29]. Multiple authors advocate for removal of all bony fragments devoid of soft tissue attachment and resection of remaining bone until actively bleeding surfaces are obtained. Extensive bony debridement can lead to significant challenges in healing as well as fracture reduction and fixation. Several methods to address large bone defects have been described in the literature; however, a detailed discussion of these is beyond the scope of this chapter.

Fracture Treatment Options

A recent meta-analysis looking at which surgical treatment for open tibial shaft fractures leads to the fewest reoperations attempted to give guidance to clinicians on the choice of fixation. Unfortunately, there are very little high-quality data to base this analysis upon, so the authors could give no strong recommendations despite this extensive and rigorous review of the literature by these authors [30]. There is currently relatively limited guidance regarding the use of each of the following treatments.

Casting

Antich-Adrover and colleagues randomized 39 patients with open tibia fractures, who were converted from an external fixator to either cast treatment or intramedullary nail. The patients had the fixator removed when the management of the soft tissue was complete. The cast group had an increased incidence of nonunion (30% vs. 6%) and malunion (50% vs. 23%). The authors concluded that casting was not an acceptable form of treatment for open tibia fractures and cast treatment is typically not employed in clinical practice for open tibia fractures [31].

Unilateral External Fixation

Definitive unilateral external fixation of open tibia fractures results in several complications when compared to IMN. Henley and associates prospectively evaluated unilateral external fixation to unreamed intramedullary nailing. Sixty-eight patients were treated with ex-fix and 104 patients with IMN. The unilateral ex-fix had a statistically higher incidence of malunion (48% vs. 8%). They did not find a difference in the time to union or union rate between the groups. Regression analysis determined that the only predictor of fracture healing was the amount of soft tissue injury. They concluded that IMN was the treatment of choice due to the more predictable alignment at healing when compared to unilateral external fixation [32]. The superiority of unreamed IM nailing over uniplanar external fixation has also been demonstrated in several randomized trials. Bhandari and associates performed a meta-analysis including five randomized and quasi-randomized trials comparing the two methods of treatment. The overall analysis combined the results from 396 patients and found a reduced risk of reoperation, malunion, and superficial infection in patients treated with unreamed nails [33].

The LEAP study group reported on the outcomes of a subgroup analysis of the Type III open tibia fractures. They found that the patients who had definitive fixation with a unilateral frame had more surgical procedures and an increased risk of infection when compared to patients who received a nail. Functional outcomes were similar only in the subgroup of patients who were treated in a frame and did not require a flap. Those that did require a flap had significantly worse functional outcomes. However, in all of these nonrandomized studies, there is risk of selection bias favoring the nail group as the patients who had the frames likely typically had worse injuries than patients who were treated with a nail [34].

Unilateral external fixation is still the treatment of choice for provisional stabilization of the infrequent open tibia fractures with significant soft tissue injury and gross contamination at our center that requires multiple debridements. Advantages include the ability to monitor the soft tissue and the chance to manipulate the fragments to adequately debride the soft tissues during multiple washouts.

Intramedullary Nail

There are good data to support immediate IMN after adequate irrigation and debridement of lower-grade open tibia fractures. Kakar and Tornetta prospectively evaluated their protocol of initial aggressive debridement and unreamed IMN followed by soft tissue coverage within 14 days. Wound closure was performed by delayed primary closure or flap. They achieved union without the need for secondary surgeries in 89% of patients (127/143 patients). They reported a 3% incidence of deep infection rate requiring surgical debridement. They concluded that unreamed IMN of open tibia fractures, with wound closure within 14 days, was safe and effective, but only 13% of these patients were IIIB (19 patients), and there were no IIIC fractures [35].

There is concern regarding the technique of reaming in open fractures because of the potential disruption of the endosteal blood supply in a fracture with already-compromised periosteal blood supply due to the open nature of the fracture. The SPRINT investigators performed a multicenter, randomized controlled trial of reamed versus unreamed tibia nails in open and closed tibia fractures. The study included 400 open fractures. There were no differences in infection or reoperation to achieve union between the two groups (the primary outcome measure). The conclusion of the paper was that there is no benefit of reaming in open tibia fractures, and delaying reoperation for nonunion for at least 6 months may decrease the need for reoperation [36].

The LEAP study group has questioned the safety of immediate nailing in severe open tibia fractures that were classified as "severe" IIIA, IIIB, or IIIC. They reported an overall infection rate of 16% in all Type III open tibia fractures. The highest infection rate (27%) was in Type IIIC fractures. The overall complication rate was between 33% and 57% for these high-energy, open tibia fractures [37].

We believe that immediate nailing of open tibia fractures is safe when performed with an adequate initial debridement. If a wound requires multiple debridements and the nail would compromise the ability to access areas of concern, we believe that the fracture should not be immediately nailed but rather placed in a temporary external fixator. Nailing of more severe type open fractures is commonly done and is reasonable but is associated with significant infection rates for these more devastating injuries.

Nailing After Provisional Ex-Fix

There is a concern that performing intramedullary nailing of open tibia fractures after external fixation may lead to an increased risk of infection due to seeding from colonized pin tract sites. Bhandari and associates performed a systematic review of the literature of IMN of tibia fractures after external fixation. There was only one prospective randomized controlled trial [31]; the remainder was level IV studies. All of the studies reviewed reported a staged technique wherein the frame is removed for a duration of time before proceeding with definitive nailing. The duration of the internal fixation between stages ranged from 2 to 224 days. They concluded that infection rates of IMN after external fixation average 9%, union rates average 90%, and the shorter duration of external fixation reduces the overall risk of infection. There is an 83% reduction in the rate of infection for frames that are on less than 28 days. If the frame is removed and IMN planned in a delayed fashion, they recommend IMN in less than 14 days. The data are likely biased as patients with longer duration of frame and a longer interval from frame removal to nail may have had worse injuries. They report a typical protocol of debridement of pin sites and antibiotic coverage during the interval from frame removal and nail [38].

Given the paucity of data, it is the authors' preferred practice that the timing of IMN after external fixation of open tibia fractures should be dictated by the soft tissue injury. As mentioned in the previous section, it is our belief that if the presence of the IMN would prevent adequate repeat debridements, the external fixator should remain in place until that is no longer the case. There are no data to guide the surgeon with regard to what to do with the pin sites at the time of frame removal. If the pin tracts are clean and without evidence of infection, we will proceed with immediate, single stage frame removal and intramedullary nail. If there is purulence from the pin sites, the frame will be removed, and the patient will be splinted and placed on IV or PO antibiotics until the pin sites are clean. Then the patient will undergo an intramedullary nail. Although it is commonly done in clinical practice, there are to our knowledge no data on the safety of immediate intramedullary nailing after the removal of external fixation of acute tibia fractures.

Plate Osteosynthesis

Plate fixation of open tibial shaft fractures is rare and has little support in the modern literature. It was more commonly used before the development of modern locking tibial nails and in an era when it was believed that open fracture was an absolute contraindication to reamed intramedullary nailing. In the only prospective, randomized trial available, Bach and Hansen report the results of 59 Grade II or III open tibia fractures treated with either plate osteosynthesis or definitive external fixation. The study predated the introduction of minimally invasive percutaneous plate osteosynthesis (MIPPO). Patients treated with plating had a significantly higher rate of osteomyelitis (19% vs. 3%) and wound infection (35% vs. 13%). There was also a 12% rate of fixation failure with plating [39].

There are two recent retrospective studies evaluating plating of open proximal or distal third tibia fractures. In their study of 34 patients with open proximal third tibial shaft fractures treated with percutaneous lateral plating, Kim and associates reported an infection rate of 26.7% with most infections in the IIIB fractures. Alignment was 5 degrees or less in all but two patients. However, given the lack of details reported in this study, we cannot conclude that plating is equivalent to nailing in the treatment of open tibia fractures [40]. In the second study, Avilucea and associates compared nailing versus plating of open distal tibia fractures. Even with significant selection bias in favor of the plating group, this group had a higher rate of nonunion and was 2.5 times more likely to develop any complication [41].

We would not generally recommend the acute use of plate osteosynthesis in the treatment of open tibial shaft fractures based on currently available data and concern for infection and nonunion, but there are very little modern data to support this recommendation.

Definitive Uniplanar External Fixator

Concerns over treatment of open tibia fractures with unilateral frames include increased incidence of malunion because of the lack of stability from the uniplanar frame. Reports of treatment with uniplanar external fixation did not use today's fixation technology with pin-bar clamps, outriggers, and multiple bars [31, 32]. Further, Webb and associates demonstrated that in the LEAP study, the use of an external fixator for definitive treatment was associated with poor outcomes. The patients treated with external fixators in this study were more likely to have had worse injuries, but these data certainly do not encourage the use of simple frames for the definitive treatment of high-grade open fractures [34]. Although we support the use of simple temporary uniplanar external fixators in many situations for higher-grade fractures, we do not use them for definitive treatment due to concern of malunion.

Ring External Fixation

The risk of infection for severe open fractures, particularly those seen in the military, has created some interest in ring fixators for definitive care of open tibia fractures. Ring fixators, like uniplanar fixators, have a theoretical advantage over IM nails as there is no metal present at the open fracture site that might promote the formation of a bacterial biofilm and lead to deep infections which are difficult to treat. The ring fixator has an advantage over uniplanar fixators that it may overcome the main limitation of malunion demonstrated in earlier studies with uniplanar external fixators for tibia fractures, because of its improved mechanical properties due to multiplanar points of fixation. The devices also allow for gradual correction of deformity and compression or distraction at the fracture site, which may be useful in managing difficult soft tissue issues as well as the ability to use distraction osteogenesis to fill in bone defects.

Hutson and associates presented 69 IIIB civilian open fractures and another series with 19 IIIB or IIIC tibia fractures with bone defects treated with ring external fixators. Despite the high-risk-type fractures contained in this series, they demonstrated an impressively low 0% rate of osteomyelitis. Malunion was also not a problem (<10%) experienced by these traumatologists who were experienced in the use of ring fixation for open tibia fractures [42, 43]. It is not known if this low infection rate is due to the use of the ring fixator, the particularly aggressive debridement used in this series or other factors specific to this center.

Noting a high infection rate in open tibia fractures treated with IMN sustained from a military blast injuries, Keeling and associates reviewed a protocol of treatment with circular external fixation in 45 high-risk open tibia fractures [44]. They noted an overall deep infection rate of 8% for all Type III injuries. All fractures healed with <5° of angulation in all planes. The average time for frame removal and healing was 220 days. This is in stark contrast to previously reported infection rates of approximately 45–50% for patients treated with unilateral frames converted to intramedullary nails.

Dickson and coworkers attempted to summarize the ring fixator literature for open tibia fractures and to compare it to the results of other fixation devices. This comparison is difficult as there is a lack of randomized data. However, in keeping with the studies by Hutson [42, 43] and Keeling [44], they did observe a very low deep surgical site infection rate of 0.9% in 420 patients collected from 11 prior studies [45]. This idea that a ring fixator might be able to reduce the risk of deep surgical site infection after the most severe open tibia fractures has a group of strong advocates but awaits data from a high-quality trial to determine its validity.

It is our practice to consider utilizing circular external fixators for definitive fixation in cases with severe Type III open tibia fractures, who are at a higher risk of infection. These patients are routinely placed in unilateral frames at the initial debridement. The unilateral external fixator often stays on for several weeks until flaps and skin grafts mature and there are no wounds needing dressing changes, as dressing changes are difficult with a circular frame in place. At that time, the patient is then converted to a circular frame.

Soft Tissue Coverage

Use of the Wound VAC

The use of vacuum-assisted closure (VAC) technology (also referred to as negative-pressure wound therapy (NPWT)) for the coverage of open wounds has become increasingly more popular. VAC treatment has been shown to increase blood flow, control edema, and result in a reduction in wound area and a move to simpler soft tissue procedures for closure [46]. VAC treatment has also been associated with lower rates of wound infection. Stannard and coworkers reported a prospective randomized study comparing the use of gauze dressings to negative-pressure wound therapy (NPWT) for open wounds, following initial irrigation and debridement of 62 high-energy open fractures. They showed a significant decrease in deep infection rate in the NPWT group (5.4% vs. 28%, $p = 0.024$) [47].

Similarly, Blum and coworkers retrospectively evaluated 229 open tibia fractures managed with either NPWT or gauze dressings as determined by the treating surgeon. Multivariate analysis adjustment for Gustilo type showed a 78% decrease in deep infection risk with the use of NPWT [48]. These studies were recently included in a systematic review looking at 13 published studies evaluating the use of VAC wound therapy in Grade IIIB open tibia fractures. The authors report VAC therapy decreased infection rate over gauze dressings in two of four studies. In addition, VAC use for >72 h showed no increased infection rate in 8/10 studies. VAC therapy was also associated with a decrease in flap rates suggesting that VAC may be able to prevent eventual flap coverage in some injuries initially classified as Grade IIIB [49].

Clinicians have wondered if the sealed nature of the VAC can reduce the association between delay in wound closure and infection after IIIB open tibia fractures as described in the following section. One group of authors found that routine use of the VAC did not prevent this association as infection was observed in 57% of patients with soft tissue coverage after a week versus 12.5% in less than a week despite use of the VAC [50].

Timing of Definitive Coverage and Evidentiary Table

The ideal timing of soft tissue coverage remains controversial, although there is a consensus that wounds should not be definitively closed or covered until all devitalized or contaminated tissues have been removed. Many papers exist that show higher infection rates when flap coverage is delayed, but these studies are significantly limited because the patients in the delayed group tend to have worse wounds or other risk factors for infection that make them more likely to become infected regardless of timing. A systematic review comprised mostly of retrospective studies with this bias confirms early flap coverage is associated with lower infection and complication rates [51].

Two reports from the LEAP study group attempt to control for this effect and concluded that timing of flap coverage was not a predictor of flap failure after controlling for factors that are likely to promote infection, such as more severe fracture classification. Early flap coverage was defined as within 3 days and compared to flap coverage after 3 days. Both studies controlled for confounding variables, such as fracture pattern and injury severity [34, 52]. D'Alleyrand reported conflicting conclusions evaluating the timing of flap coverage and also controlling for confounding variables. This study concluded that there was no increased risk of infection or complications at less than 7 days. After 7 days, however, they found an increase of 16% and 11%, respectively, per day. Differences between the findings of these studies' results may be related to the definition of "early" flap coverage [53].

Lenarz and coworkers reported an algorithm for closure in 346 open fractures, using objective culture results after irrigation and debridement that decreased the risk of infection in Type II and III open fractures. Timing of closure was dictated by the results of cultures taken at the time of each irrigation and debridement. If the cultures were negative, the wound was closed. If cultures were positive, then the wound underwent a repeat irrigation and debridement. If the cultures turned positive after definitive wound closure, the patient did not return to the operating room unless the wound was suspicious for infection, but the patient was given an extended period of IV antibiotics of up to 6 weeks, depending on the organism. These data certainly do not provide level I evidence, but the infection rates for Type I (0%), Type II (3.2%), Type IIIA (2.2%), Type IIIB (4.2%), and Type IIIC (21.4%) were all less than historical controls and provide provocative data for further work [20].

It is the authors preference that definitive wound closure should be performed at the earliest time period that is feasible once all gross contamination is cleared and nonviable tissue is removed and ideally within 7 days of injury if possible (Table 23.1 [2, 10, 24, 27, 36, 38]).

Definitive Treatment Plan

Our best recommendation for the treatment of our case patient (MI) is for prompt initiation of combination IV antibiotic therapy with cefazolin and possible additional gram-negative coverage. Tetanus should be updated as needed. In the setting of gross contamination, we favor the earlier surgical irrigation and debridement and certainly within 24 h if the patient can safely tolerate this procedure. In this severe situation, we might be inclined to treat initially with a temporary uniplanar external fixator. After aggressive debridement of devitalized soft tissue and bone, and irrigation with at least 9 L sterile saline, our recommendation is for wound coverage with an antibiotic bead pouch. Initial irrigation and debridement are followed by planned return to the operating room for serial debridements every 24–48 h and placement of a new bead pouch until the tissues are ready for definitive soft tissue coverage. Given the size of this patient's initial wound, a free or rotational flap will likely be needed. At this point, there are strong arguments to be made for using either a ring fixator or IM nail as definitive fixation, and we commonly use both in our practice in this situation. However, if soft tissue coverage is unable to be performed within the first 14 days or infection develops prior to definitive fixation, a multiplanar (ring) external fixator is used for definitive fracture fixation to minimize infection risk. The less severe the wound, the more likely we are to use IM nails in this situation, but this is based on preference and not supported in the literature.

Table 23.1 Evidentiary table: A summary of evidence supporting preferred treatment for open diaphyseal tibia fractures

Author (year)	Description	Summary of results	Level of evidence
SPRINT study group (2008) [36]	Prospective randomized	400 open tibia fractures treated with IMN. No advantage to reaming, and an infection rate of 9%	I
Bhandari et al. (2005) [38]	Meta-analysis	Infection rates average 9% after conversion of ex-fix to IMN. Length of ex-fix of <28 days reduces risk of infection	II
Gosselin et al. (2004) [2]	Cochrane review	Review and weighted analysis of the literature concluded that antibiotics are effective in reducing infection in open fractures	I
Schenker et al. (2012) [24]	Meta-analysis	Meta-analysis of 3539 open fractures showed no difference in infection rate between early and late debridement defined by 5,6,8, or 12 h	III
Lack et al. (2015) [10]	Retrospective prognostic	Antibiotics administration greater than 66 minutes from injury and wound coverage greater than 5 days were independent predictors of infection in type III fractures	II
FLOW Investigators (2015) [27]	Prospective randomized	Higher reoperation rate in patients randomized to soap irrigation compared to saline. No difference in the reoperation rate when comparing low versus high pressure	I

Predicting Outcomes

An understanding of functional outcomes following severe open tibia fractures is important for providing reasonable expectations for the patient and for providing guidance in the choice between limb salvage and amputation for more severe open tibia fractures. Unfortunately, objective measures to allow the surgeon to predict the functional outcome of any given patient following a severe open tibia fracture are limited. Multiple authors have shown that previously used injury severity scores (including the Mangled Extremity Severity Score and Limb Salvage Index, among others) fail to adequately predict outcome [54, 55].

However, multiple studies have presented evidence of poor functional outcomes irrespective of treatment method. MacKenzie and coworkers reported overall poor 7-year functional outcomes for patients following severe lower extremity trauma in general [56]. Functional outcomes after amputation were similar to those after limb salvage. Half of the patients studied had substantial disability. Patient factors found to correlate significantly with poorer outcome were older age, female gender, nonwhite ethnicity, lower education level, poor household, current or previous smoker, low self-efficacy, poor pre-injury health, and involvement with the legal system. In another analysis of patients from the LEAP study, Castillo and coworkers showed a significantly higher level of chronic pain than the general population ($p < 0.001$) on par with chronic pain associated with migraine and low back pain [57]. In the SPRINT trial, open tibial shaft fractures also had poorer outcomes than closed injuries. The rate of reoperation or autodynamization within 1 year of injury was 26.5% in open injuries compared to 13.7% for closed fractures [36].

Outcomes in studies of military personnel are similarly poor but may show an advantage of amputation over salvage in the military setting. The METALS (Military Extremity Trauma Amputation/Limb Salvage) study reported poor outcomes in both the salvage and amputation groups with high rates of depressive symptoms (38%) and PTSD (17.9%) with one third (34.0%) of patients not working, on active duty, or in school. In both groups, SMFA scores were significantly worse than population norms. However, after adjustment for covariates, the amputation patients had better scores in all SMFA domains compared with those in the salvage group ($p < 0.01$). Improved outcomes following amputation in military patients may be a result of unique social and rehabilitation support as well as access to new prosthesis technology [58]. Therefore, care must be taken when comparing these results to those in civilian populations.

Overall there are few high-quality prospective data that help clinicians understand the functional outcomes after open tibia fractures and how modifiable treatment parameters or risk factors affect these outcomes. This is an area of continued future research.

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Part VI

Foot and Ankle Trauma

24 Pilon Fractures

Basem Attum, Vamshi Gajari, David P. Barei, and A. Alex Jahangir

JA: 47-Year-Old Male with Ankle Pain

Case Presentation

JA is a 47-year-old male who presents to the emergency department with a chief complaint of right leg and ankle pain after falling 12 ft from a ladder and landing on his right leg. He denies pain in any other extremity or his back and is unable to bear any weight on his right lower extremity. On primary survey he demonstrates a GCS of 15 and a patent airway and is hemodynamically stable. On secondary survey, no gross deformity is noted of his right lower extremity.

His past medical history is negative, he takes no medications, and he has no allergies. Physical exam demonstrates a healthy appearing male in no acute distress. Exam of his right leg demonstrates a gross deformity to the right ankle with moderate swelling. No open wounds are present. The dorsalis pedis and posterior tibialis pulses are palpable and equal to the contralateral extremity. Sensation to light touch is intact in all dermatomal distributions. Right leg compartments are soft and compressible. The patient is able to move all of his toes in plantar and dorsiflexion.

Radiographs and CT scan images of his right ankle are demonstrated in Figs. 24.1a–c and 24.2a–g.

Interpretation of Clinical Presentation

This patient's findings and symptoms are consistent with a significant injury to the ankle. The history of a 12-ft fall from a ladder landing on the right leg suggests an axial loading mechanism, and the plain radiographs of the ankle confirm an intra-articular fracture involving the tibial plafond. An associated comminuted fracture of the lateral malleolus is also identified. Specifically, the plain radiographs demonstrate a complete articular injury with fracture shortening and medial and anterior translation of the distal (talar) segment, with varus and extension angulation. Though involving both the medial and lateral malleoli, this injury should not be confused with the more commonly encountered malleolar fractures and fracture-dislocations that occur from lower-energy rotational mechanisms. The term "pilon" fracture is commonly applied to injuries of the tibial plafond and is a descriptive mechanistic

B. Attum · V. Gajari · A. A. Jahangir (✉)
Department of Orthopedic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA
e-mail: alex.jahangir@vanderbilt.edu

D. P. Barei
Harborview Medical Center, University of Washington, Department of Orthopedics, Seattle, WA, USA

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Fig. 24.1 (**a**) Mortise radiograph ankle (**b**) AP radiograph ankle (**c**) Lateral radiograph ankle

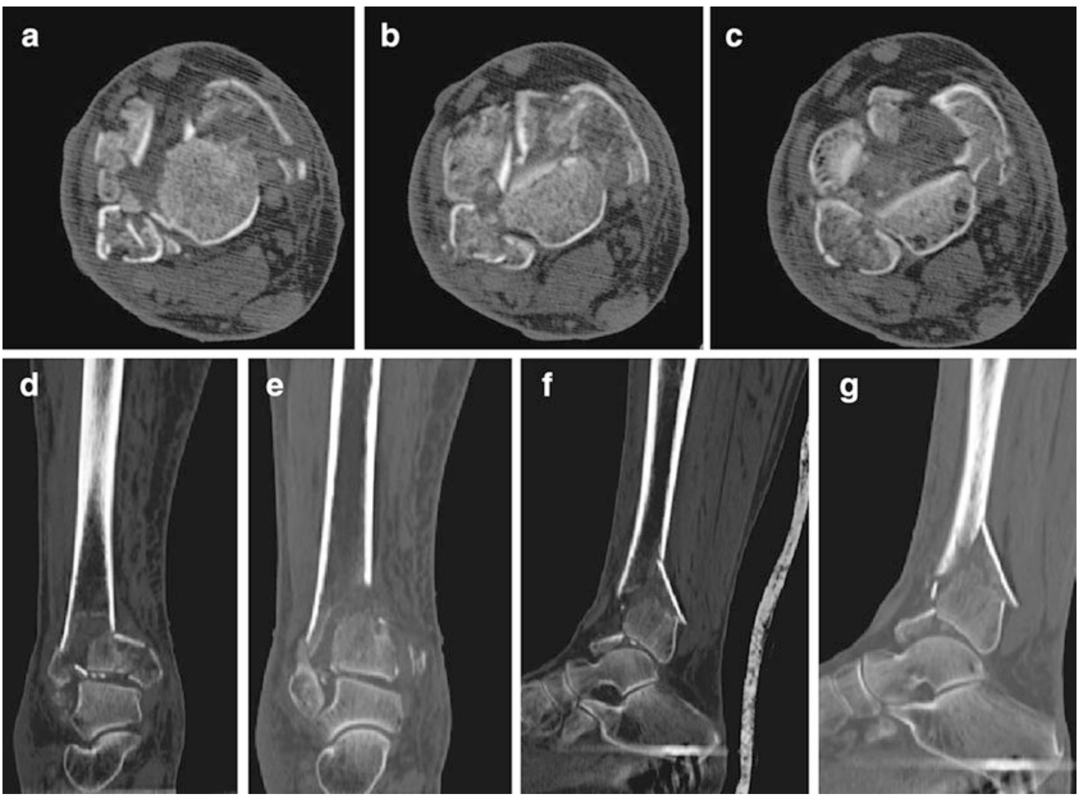

Fig. 24.2 (**a–c**) Axial CT tibia (**d, e**) Coronal CT tibia (**f, g**) Sagittal CT tibia

expression, where the talus can be considered a pestle that impacts the distal tibial plafond within the confines of the mortise. The axial loading forces that occur when the talus is forced proximally into the distal tibia produces an explosive fracture of the articular surface [1]. The energy absorbed by the limb often produces significant osseous comminution, fracture displacement, and translation. The substantial soft tissue injury that often occurs is manifested in the form of swelling, serous and hemorrhagic blisters, deep abrasions, and, occasionally, open wounds. Substantial swelling with the formation of fracture blisters may form within a few hours of the initial injury. Compartment syndrome associated with tibial pilon fractures that do not have significant diaphyseal extension is rare but has been reported [2]. Pilon fractures can be considered a severe soft tissue injury that happens to have a fracture.

Because of the higher-energy mechanisms frequently responsible for these fractures (such as those that occur with falls from a height or motor vehicle collisions), the emergency room evaluation should include an assessment of the patient's general condition, including other areas of pain. Fractures of the spine should be excluded clinically and/or radiographically. In several large series of tibial plafond fractures, other fractures and other major system injuries were present between 27% and 51% of the time [3–9]. Full-length plain radiographs of the tibia and fibula, and appropriate radiographs of the foot, complete the plain radiographic assessment.

The initial radiographic workup includes an axial CT scan with coronal and sagittal reformations. Major fracture cleavage planes, areas and magnitude of articular comminution and impaction, and the relationships of the lateral distal tibial articular surfaces relative to the fibula at the syndesmosis can all be accurately assessed and considered. CT scanning of tibial plafond fractures has been demonstrated to improve the ability to assess the fracture and formulate a preoperative plan before definitive fixation [10, 11]. Tornetta prospectively assessed 22 patients with intra-articular distal tibial fractures using plain radiographs and CT scans. The plain radiographs were assessed initially, and the fracture pattern, number of fragments, presence of comminution, and impaction were documented. The CT scan was then reviewed, and any changes in the fracture features and in the operative plan were similarly recorded. With the information obtained from the CT scan, the authors demonstrated a change in operative plan in 64% of cases and additional fracture characterizations occurred in 82% of cases. Topliss and colleagues reviewed the CT scans of 126 consecutive pilon fractures and performed an extensive anatomic description of the major fracture lines at the level of the tibial plafond. The authors identified ten types of pilon fractures that could generally be grouped into either sagittal or coronal plane injury patterns. Sagittal plane injuries were associated with higher-energy injuries, varus angulation, and younger age. Conversely, coronal plane injuries were associated with valgus angulation in older patients after less severe trauma. While not definitively proven, it is a reasonable practice to perform the CT scan *after* a provisional reduction of the distal tibia has been performed.

Initial management in the emergency room consists of a gentle realignment of the limb, repeat assessment of the pedal pulses, and application of an above-the-knee plaster splint to provide pain relief and minimize further soft tissue injury. The limb should be elevated above the heart to decrease swelling.

Declaration of Specific Diagnosis

JA is a 47-year-old male who presents with an axial loading comminuted closed tibial pilon fracture with an associated distal fibula fracture.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Anatomic restoration of the distal tibial articular surface
2. Anatomic restoration of tibial and fibular alignment
3. Minimization of further soft tissue injury
4. Early functional rehabilitation including ROM of the foot and ankle
5. Return to realistic employment and realistic life activities

Treatment options include the following:
Conservative/non-operative treatment:

1. Casting
2. Skeletal traction

Surgical:

1. Immediate open reduction and internal fixation (ORIF)
2. Staged ORIF
3. External fixation (with or without formal arthrotomy, limited incision, or percutaneous articular reduction/fixation)
   (a) Tibiotalar sparing
   (b) Transarticular spanning
   - Articulated
   - Nonarticulated

Evaluation of the Literature

In order to identify relevant publications on intra-articular tibial plafond fractures, electronic Medline and PubMed searches were performed. Keywords included the following: "distal tibia* *and* fracture treatment," "intra-articular distal tibia* *and* fracture treatment," and "tibia* *and* pilon *or* plafond fracture treatment." All searches were limited to publications from January 1, 1975 to 2011, English language, human subjects, and chronological adults (>19 years of age). This search identified 447 abstracts that were reviewed. From this, 135 publications were read, and their reference lists were reviewed. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

Conservative/Non-operative Treatment

Several decades ago, purely conservative treatment of these injuries using closed reduction and plaster cast stabilization had largely been demonstrated to have relatively poor functional results, resulting in its abandonment in favor of operative therapy. Several authors have noted the same consistent difficulties with cast treatment: (1) The inability to maintain the talus from its common displacement anteriorly and superiorly, (2) the inability to accurately realign or reduce displaced osteochondral fracture fragments, and (3) the trophic impairments secondary to prolonged joint immobilization [12]. In 1971, Ruoff and Snider published a series of "illustrative cases." Using these cases and their expert opinions, the authors suggested surgical tactics to specifically remedy the deficiencies of non-operative methods. Cast treatment is ineffective at achieving our desired therapeutic goals, and while it does represent the minimum risk for soft tissue injury, skin necrosis complications may still occur secondary to local skin ischemia from displaced fracture fragments.

The use of a calcaneal pin placement and traction to mechanically counteract displacement vectors was previously noted to have satisfactory results [13]. Using ligamentotaxis, skeletal (calcaneal pin) traction improves tibial alignment, length, and the position of the talus beneath the tibia but is still suboptimal in achieving satisfactory articular reduction, particularly with impacted articular fragments. However, the prolonged recumbency for this technique is challenging and prone to the complications of general immobility and patient compliance.

While treatment goal 3 can be achieved with conservative treatment, goals 1, 2, 4, and 5 cannot realistically be achieved, and therefore surgical intervention should be strongly considered. Non-operative management is useful but is ideally reserved for truly nondisplaced fractures or for those patients that have a significant or absolute contraindication to operative treatment. Since this patient appears to be a healthy and active patient with a significantly displaced intra-articular tibial plafond fracture, the author recommends operative intervention.

Operative Treatment

Immediate Open Reduction and Internal Fixation

Ruedi and Allgower's seminal English language manuscript in 1969 described a principled technique for ORIF of the tibial plafond that demonstrated a substantial improvement in functional outcome, complications from arthrosis, and a minimal treatment complication rate compared to non-operative management [14]. This landmark article would become the benchmark for the treatment of these injuries, since only 3 of 84 consecutive patients developed a deep wound infection. Subsequent to this publication, the history of open reduction and plate stabilization of tibial plafond fractures in North America demonstrated a marked increase in deep wound infection rates and complications with associated poor outcomes. Bourne reported on ORIF of 42 tibial pilon fractures and noted a 14% deep infection rate with 85% nonanatomic reductions in comminuted fracture patterns [1]. In their 5-year experience with internal fixation of pilon fractures, McFerran reported a 40% major complication rate, the majority due to soft tissue complications and infections [15]. Injury mechanisms were not specifically outlined, but 40% of the 52 fractures evaluated were of polytraumatized patients, likely indicating a higher-energy mechanism. The mean time to definitive surgery in this group was 4.7 days, the median time was 3 days, and 46% were treated within 36 h. The authors, however, did not find any statistical association between time to surgery and wound complication. Teeny and Wiss evaluated 60 tibial plafond fractures treated with open reduction and plate fixation, noting that poor results occurred in 50% of cases, with a 37% deep infection rate in comminuted pilon fractures [16]. In this study, the average time to operation for closed fractures was 5.6 days. Sixty percent of these injuries were from high-energy mechanisms including motor vehicle collisions and falls from greater than 3 m in height, with the latter finding strongly correlating with a surgical postoperative wound infection. Wyrsch and colleagues, in a prospective study, reported a near 40% soft tissue complication rate in patients treated with primary ORIF [17]. All of the fractures in this study occurred from motor vehicle accidents or falls/jumps from a height. The average time from injury to operative fixation for closed fractures was 5 days; however, the goal was for fractures to be operatively stabilized within 48 h unless "severe swelling or fracture blisters were present." All of the preceding authors recognized that ORIF techniques in a previously underappreciated traumatized soft tissue envelope were a causative factor in the development of significant wound complications and poor outcomes.

At least two major differences can be identified between Ruedi's study and those with higher complication rates noted above: (1) the time delay from injury to definitive surgery and (2) the mechanism of injury. Though not often noted, 75% of Ruedi's patients were definitively managed surgically on the day of their injury. Fourteen patients were delayed for over 7 days secondary to "severe swelling or doubtful skin conditions", and the remaining six patients had been treated initially with casting elsewhere, but the exact time to their definitive procedure was not indicated. Importantly, of the 84 fractures in Ruedi's manuscript, 60 fractures (71%) occurred from skiing injuries, 19 fractures (23%) occurred from a fall between 3 ft and 12 ft, and only 5 fractures (6%) occurred from higher-energy traffic accidents. Comparatively, the manuscripts indicated above describe a time delay between injury and definitive treatment between 3 and 6 days. Furthermore, they also describe a greater proportion of their patient population as having sustained their injuries from higher-energy motor vehicle collisions or other industrialized mechanisms. Tang's study on 46 patients comparing closed type C pilon fractures who underwent surgery within 36 h of injury or delayed treatment found no significant difference between groups regarding the rate of soft tissue complications, fracture union, and final functional score. The early fixation group had a significantly shorter mean time to fracture union (21.5 ± 4 weeks vs. 23.3 ± 3.7 weeks, $p < 0.05$) and hospital stay (7.6 ± 2.6 days vs. 15.2 ± 4.2 days, $p < 0.01$) [18].

Obviously, many other factors may also be responsible for the differences in outcomes and complications, including the experience of the surgeons, achievement of fracture stability, and other perioperative variables that were poorly controlled. Timing and injury mechanisms, however, remain and have shaped the evolution of tibial pilon fracture care over the past 30 years.

Intuitively, ORIF is easiest to perform immediately after injury and before the development of organizing hematoma, soft tissue contraction, callus formation, and inflammatory osteopenia has occurred. White and colleagues revisited the concept of acute ORIF of comminuted tibial pilon fractures [19]. The authors reported on 95 patients injured in relatively high-energy mechanisms treated using current ORIF techniques by trauma surgeons facile in the management of these injuries. Eighty-eight percent were definitively managed within 48 h, and the median time to definitive fixation was 18 h. The authors noted a 2.7% deep infection rate for closed fractures, a 19% deep infection rate for open fractures, and an overall deep wound sepsis rate of 6%. Ninety percent of the 68 available radiographic series (72% of the original cohort) were determined to have anatomical reductions. Similar to Ruedi and Allgower's work, the authors noted that a minority of patients still could not be managed with immediate ORIF, including those with severe soft tissue injuries and polytrauma patients with multisystem injury, some complex associated proximal tibia fractures, or fractures that were not amenable to primary ORIF. Overall, a high quality of reduction was noted with a medium-term outcome that compares favorably with other modalities of treatment.

In summary, immediate ORIF of this patient's tibial pilon fracture is a viable option. Factors that are critical for success include the execution of definitive treatment within 48 h of injury, a skilled surgeon with experience in the management of this injury, and a facility with adequate resources. To avoid the complications seen two decades ago, repeated series of acute ORIF in higher-energy mechanisms should be obtained to corroborate the findings of White prior in generalizing this technique. However, this patient's injury should be approached with caution as his injury mechanism and radiographic investigations indicate this to be a higher-energy axial loading (not torsional) injury.

Staged Open Reduction and Internal Fixation

Because of the problematic soft tissue complications associated with ORIF, a substantial reassessment of the optimal treatment for these injuries has occurred over the last two decades.

In particular, resurgence in the treatment of tibial plafond fractures with ORIF techniques, but with strict attention to the critical appreciation and handling of the traumatized soft tissue envelope, and performing definitive ORIF only after a period of soft tissue recovery has occurred.

This has led to the popularization of the staged management of tibial pilon fractures, emphasized in 1999 by two separate reports by Sirkin, Sanders, and colleagues [20] and Patterson and Cole [21]. These studies concluded that the historically high rates of infection associated with ORIF of pilon fractures may have been due to attempts at early fixation through swollen and compromised soft tissues. Though Sirkin's and Patterson's separate manuscripts firmly placed the staged ORIF management of tibial pilon fractures into the surgeon's armamentarium, numerous other authors had previously alluded to delaying ORIF until the swelling of the soft tissue envelope had ebbed [5, 14, 22, 23]. While staged treatment remains the current foundation for the management of these injuries, the application of minimally invasive plating techniques, the use of alternate exposures, the development of low-profile and anatomically contoured plates, and a greater understanding of the osseous fracture anatomy have, in part, also been a response to the difficult soft tissue injury that accompanies these fractures. These latter confounding variables likely also play a role in lowering wound complication rates.

Sirkin's influential study popularized staged treatment of tibial pilon fractures [20]. In that study, the authors acutely (within 24 h) managed displaced tibial plafond fractures with a closed manipulative reduction and the immediate application of a simple temporary transarticular external fixation device. When fractured, open reduction internal fixation of the fibula was also performed acutely. Definitive ORIF of the tibia was then performed at an average of approximately 13 days later in the closed fracture group and 14 days later in the open fracture group. The time to definitive tibial fixation was predicated on resolution of edema and was a clinical determination. Using this technique, a dramatic decrease in early soft tissue complications and later problems of osteomyelitis and deep sepsis were noted. In a total of 46 fractures, the authors identified only 3 deep septic complications, 2 of which occurred in open fractures. Using a similar protocol, Patterson and Cole had no cases of superficial or deep wound complications in 21 patients, followed an average of 22 months [21]. Twenty-one fractures healed within 4.2 months with a 40° arc of ankle flexion/extension. Using objective outcomes described by Burwell and Charnley in 1965 (including motion of the foot and ankle, swelling, gait, and the presence of visible deformity), 91% of patients had a good or fair result. There was one nonunion, one malunion, and two patients requiring arthrodesis (9%) during the study time frame.

In contrast, Bacon evaluated their results of staged treatment of 25 comminuted tibial pilon fractures and noted a substantial complication rate, including 16% nonunion, 8% malunion, and a 20% incidence of osteomyelitis [9]. In this study, the mean time to definitive ORIF was 14.7 days (±7.6 days). Two patients required tibiotalar arthrodesis because of posttraumatic ankle arthritis (8%).

A retrospective review by Bonato and colleagues on 91 operatively managed pilon fractures found that at 12 months, 57% had returned to work, the median IQR pain score was 2 (0–5), and 27% reported moderate to severe persistent pain concluding that even in the best of circumstances, persistent pain, loss of physical health, and low return to work rate are complications of pilon fractures. Mean PCS-12 scores were 38.2 for males and 37.5 for females which was significantly less than the norm ($p = 0.99$). Return to work rates were increased for those without any other injuries (not statistically significant) but worse for workers' compensation patients and AO/OTA type 43C fractures [24]. Howard, conversely, evaluated 42 patients with 46 tibial plafond fractures treated with staged ORIF [25]. This prospective cohort study specifically evaluated the location of a variety of combined surgical incisions and wound complication rates, and in turn noted a 9% soft tissue complication rate with only one deep wound infection (2%); the remaining soft tissue complications were noted to be superficial skin slough. Details regarding the adequacy of reduction, arthrosis, and functional results were not given.

Surgical approach to pilon fractures is dictated by location of the articular injury (column) and the mechanically appropriate fixation. The anterior approach is a minimally invasive approach indicated primarily for extra-articular (AO/OTA 43A fractures) which plays very little role in fractures with any degree of intra-articular involvement. The medial approach is beneficial in that it allows exposure toward the anterior metaphyseal area and articular surface permitting direct reduction of any simple intra-articular split in this plane. The anterolateral approach is indicated for pilon fractures involving the lateral column, anterior and anterolateral type B fractures, type C fractures with articular injury laterally, and cases of a valgus deformity requiring a lateral buttress plate. One disadvantage of this approach is the lack of access to the medial column. The lateral approach has the same indications as the anterolateral approach. Although the incision and initial dissection is different, the deep portion of the lateral approach arrives at the same location as the anterolateral approach. The extensile approach is indicated for the group of fractures that result in complete separation of the three columns of the tibia from the metaphysis or diaphysis [26].

These different approaches to the tibial plafond can result in variable outcomes. When comparing the anterolateral approach to the medial approach, Deivaraju and colleagues determined that satisfactory reduction can be achieved by both approaches (14/15 anterolateral approach vs. 17/18 medial approach, $p < 0.001$). Soft tissue complications were also found to be similar (4/15 anterolateral approach vs. 5/18 medial approach, $p = 0.61$). The differences seen between the anterolateral and the medial approach were in nonunion rates (0/15 vs. 4/18 $p = 0.012$), malunion rates (1/15 vs. 3/18 $p = 0.78$), and deep infection (4/15 vs. 6/18 $p = 0.03$), respectively [27].

Grose reported on staged ORIF of 44 tibial pilon fractures treated using a lateral approach [8]. Initial management consisted of temporary spanning external fixation followed by a single lateral approach to address both the fibula and tibial fractures once the soft tissue injury had time to “defervesce.” The authors demonstrated anatomic or good fracture reductions in 93%. Four patients developed a nonunion (9%), two patients developed a wound dehiscence (4.5%), and two deep infections were identified (4.5%). Assal described the staged management of 21 high-energy tibial plafond fractures treated with an extensile anterior surgical exposure and plate stabilization. The average time delay from injury to definitive fixation was 16.4 days. Patients were followed for a minimum of 12 months, and only one patient developed a local infection at the most proximal portion of the surgical exposure, felt to be secondary to contamination from the previously placed temporizing external fixator. Clinical outcomes, motion, radiologic assessment, and other health impairment parameters were not assessed in this study.

Boraiah recently evaluated the outcome of ORIF of open tibial pilon fractures using a staged protocol [28]. Fifty-nine patients with adequate follow-up formed the study population. Fifty of these patients underwent staged ORIF with the initial management directed at the debridement of open wounds and application of an ankle joint-spanning external fixator to regain length, alignment, and rotation. Definitive ORIF occurred when the soft tissue swelling had resolved. In this challenging group of injuries, the authors noted a deep wound infection rate of 3% and a superficial wound infection rate of 5%.

In summary, staged ORIF of high-energy tibial pilon fractures has, for the most part, demonstrated an improvement in wound complication rates commensurate with those seen in the initial Ruedi and Allgower manuscript described above. Overall, a deep wound sepsis rate of approximately 2–5% for closed fractures is a reasonable estimate, with higher rates likely in open fractures. Staged treatment requires the early application of at least spanning external fixation with or without fibular fixation. Critical elements are the restoration of limb alignment, length, and rotation and placement of external fixator pins well outside the area of potential surgical exposures or anticipated definitive implants. The definitive tibial reduction and stabilization occurs once there is clinical resolution of edema and re-epithelialization of fracture blisters. Reduction is commonly through an anterior surgical exposure with minimization of fracture fragment devitalization.

External Fixation

External fixation has evolved as a potential option for the definitive management of tibial pilon fractures. The most common rationale for the use of external fixation is to obtain and maintain reduction of the distal tibial metaphyseal fracture, obviating the need for plate stabilization of this area, thereby decreasing the risk of significant wound complications associated with open plate fixation. Two main external fixation constructs are available: those that span the ankle joint and those that do not. Typically, ankle-spanning systems are comprised of a unilateral fixation frame anchored at the medial border of the shaft of the tibia, the calcaneus, and the talus, creating a bridge across the ankle joint. The ankle-sparing systems are typically a hybrid of the unilateral frame and the circular, tensioned wire system, or a completely tensioned wire system with circular rings popularized by Ilizarov. The former system consists of a fixation ring applied distally with tensioned wires used to connect the epiphysis to the circular portions of the frame, and half pins placed into the tibial diaphysis proximally. A version of the ankle-spanning system has the potential to be articulated, allowing the theoretical benefits of ankle motion while still maintaining stability of the distal epiphyseal fracture segments during the osseous healing phase. When using external fixation devices, the surgeon has the option of managing the articular reduction with true open reduction techniques via standard incisions and approaches or using limited incisions combined with percutaneous screw insertions.

Numerous publications exist that examine the use of external fixation constructs for the management of tibial plafond fractures. The manuscripts have the same methodologic problems as those that are associated with ORIF, namely, relatively small patient series evaluated in a retrospective manner, with variation in surgical techniques that make direct comparisons between and among studies difficult.

Papadokostakis and colleagues performed a systematic review of tibial plafond fractures treated with external fixation devices [29]. A total of 15 articles that met a satisfactory threshold for inclusion were evaluated. Four hundred sixty-five fractures were eligible for inclusion. Ninety percent were considered high-energy injuries and 71% were comminuted complete articular injuries. Minor infections (pin track or superficial wound infections) were noted in 127 of 465 fractures (27.3%). Major infections (deep, intra-articular, or osteomyelitis) were identified in 15 of 465 fractures (3.2%). The incidence of nonunion could be evaluated in 12 of 15 studies comprising 361 fractures; 21 cases were identified (5.8%). Similarly, the incidence of malunion could be evaluated in 12 of the 15 included studies, with a cumulative study population of 353 fractures. Thirty-four malunions were identified (9.6%). A greater proportion of malunions were noted in studies that utilized ankle-spanning external fixation frames; however, a greater proportion of complete articular injuries (OTA C-type fractures) were treated with ankle-spanning frames, potentially confounding this association.

The historic complication rate of ORIF of tibial pilon fractures has allowed external fixation to emerge as a viable treatment method for these injuries. While clearly superior in terms of wound complication rates when compared with the open methods published by Dillin, Bourne, McFerran, Teeny, Wrysch, and others, their superiority is marginal when compared with acute ORIF published by Ruedi and later by White. Arguably, the superficial and deep wound complication rates between external fixation [29] and staged ORIF are similar [8, 20, 21, 25, 30–32].

Richards et al. observed similar results when comparing 60 patients in a prospective cohort study comparing definitive ORIF versus external fixation. All patients received external fixators, which were in place for a mean duration of 2.29 ± 0.70 weeks for the EF group and 3.03 ± 2.18 weeks for ORIF group before having definitive fixation. Twenty-seven of thirty-four of the ORIF group and eighteen of twenty-six of the EF group completed 12 months of follow-up. There was no statistically significant difference in planned bone grafting <6 weeks post-injury ($p = 0.87$), wound infection, and wound breakdown rates in open fractures ($p = 0.33$). In the ORIF group, 3.7% of the patiens developed nonunion when compared to 22.2% in the EF group ($p = 0.05$). At the 12-month follow-up, all fractures in the ORIF group achieved union while one fracture in EF group did not show union on radiographic imaging. Postoperatively, six patients in the ORIF group had higher Iowa ankle scores (23 ± 12.1 vs. 11.1 ± 7.7; $p = 0.002$) and SF-36 (49.7 ± 30.1 vs. 25.5 ± 18.0, $p = 0.03$) when compared to the EF group. At 12 months Iowa ankle range of motion was significantly increased in the ORIF group (5.5 ± 2.2 vs. 3.1 ± 1.7, $p = 0.009$) [33].

External fixation is an option for the management of this patient's tibial pilon fracture. A feature that makes this challenging, however, is the extreme distal nature of the fracture that invariably will require an ankle-spanning fixation device. The significant articular comminution, particularly that involving the anterior half of the plafond, will require a manipulative reduction at a minimum. Failure to address the anterior plafond and, hence, the anterior buttress to anterior talar extrusion is likely to result in early loss of joint function and a poor result. Importantly, the primary rationale for using external fixation for tibial pilon injuries is to neutralize the metadiaphyseal component of the fracture. Because the extent of JA's injury is essentially epi-metaphyseal, with virtually no extension into the diaphysis, the utility of external fixation is minimized.

Minimally Invasive Plate Osteosynthesis ("Biologic Fixation")

The entire treatment of tibial pilon fractures continues to be an evolution in "biologic fixation," and to ascribe this term to a single treatment modality is a misnomer. For our purposes, "biologic fixation" of tibial pilon fractures refers to indirect reduction and percutaneous plate fixation of comminuted tibial pilon fractures. Using minimally invasive plate osteosynthesis (MIPO), the articular injury is typically reduced using direct exposures and manipulations or percutaneous adjuncts. Once the articular surface is reduced, the metadiaphyseal component of the fracture is indirectly reduced and stabilized with a percutaneously applied plate/screw implant. It is ideally suited for tibial pilon fracture variants that have extensive metadiaphyseal comminution not amenable to direct reduction without extensive exposure(s) which potentially risk devitalization of the fracture fragments.

Eight studies using percutaneous plate fixation of distal tibial plafond fractures were evaluated [34–41]. All were retrospective series with limited patient numbers and historical comparison groups. The purpose of most of these manuscripts was the documentation of complications. A total of 189 distal tibia fractures were included, and 144 were noted to have intra-articular involvement. Eighteen fractures were open. When considered overall, ten fractures were complicated by superficial wound healing problems (6%), and four had significant deep wound complications or dehiscence that demonstrated exposed implants (2.5%). There were nine cases (5.5%) that demonstrated abnormalities in fracture healing, including delayed unions requiring operative intervention, nonunions, or malunions.

Four studies included functional data as part of their results. Bahari and colleagues evaluated 48 distal tibia fractures treated with MIPO and found an SF-36 score of 85 and an AOFAS of 90 at approximately 1.5 years post-injury [34]. Both of these scores indicate high function with the SF-36 score similar to that of the normative population. Thirty of these fractures were intra-articular, but only three were comminuted and classified as type III according to Ruedi. Borens evaluated 17 C-type intra-articular distal tibia fractures and noted that 47% had an excellent result using a modified hindfoot score, and 53% had only a fair or poor result [35]. In this study, approximately half of their group had comminuted C3 articular injuries.

Vidovic's study on 21 patients had an average time to union of 19.7 weeks (12–38 weeks), mean range of motion of 10° (range of 5–15°) dorsiflexion and 28.3° (range of 20–35°) plantar flexion. Complications included painful hardware (2/21), wound breakdown (1/21), delayed union (2/21), and fracture union of asymptomatic tibial recurvatum of approximately 10° without any functional impairment (1/21) [42]. Tong's retrospective study on 29 patients after staged management with a mean follow-up of 24 months had an average union time of 6.7 months (range of 5–11.5 months), no superficial infections, deep infections, or wound healing problems with all ankles functional at 24 months [43]. A similar retrospective review on 2-staged operative management of 25 (AO/OTA) type C closed pilon fractures conducted by Cheema and colleagues shows similar results. Patients received the first stage of fixation within 1 day of the injury. Eighty percent (20/25) of patients who had an additional fibular fracture or lateral malleolar fracture underwent internal fixation of fibula with a one-third tubular plate and medial spanning external fixator. The second stage of the procedure was performed after a mean duration of 12 days (range of 8–14 days) from the injury using standard low-profile medial distal tibial metaphyseal plate with a formal anteromedial approach in 18 patients and minimally invasive percutaneous plate performed in the remaining 7. Twenty-three of twenty-five achieved union. Complications included two nonunions, two superficial infections, and one post-traumatic arthritis [44].

The management of any tibial pilon fracture should be as biologically friendly as possible. The benefit of minimally invasive plate osteosynthesis is maximal in patients with extensive metadiaphyseal comminution and large, minimally comminuted articular fracture fragments. JA demonstrates a low articular injury with substantial articular comminution, and as such, an open exposure for the articular surface is where the majority of the surgical reduction and stabilization needs to be done. However, proximal plate fixations can be accomplished with percutaneous techniques to minimize unnecessary dissection and devitalization.

Comparative Studies

A number of studies have attempted to directly compare the results of tibial pilon fractures treated with external fixation or open methods. Several of these studies share one or more of these significant limitations: retrospective data assessment, nonrandomized patient allocations, differing injury severity, limited patient follow-up, relatively small patient sample sizes that result in underpowered statistical analyses, and variations in surgical treatments.

In 1996, Wrysch reported a prospective surgeon randomized study alluded to earlier [17]. There were 18 patients treated with ORIF, and 20 were treated with external fixation with minimal incision articular reductions. The authors noted that the complications after ORIF tended to be more severe (with three of the ORIF patients ultimately requiring amputation) than those encountered in the external fixator group, though no formal statistical analysis was done. Additionally, they noted that there was no significant difference in the degree of osteoarthrosis or clinical scores based on the treatments provided but that more displaced and comminuted fractures had lower scores. Given the higher complication rate (10% amputation in the ORIF group) and similar outcomes, the authors concluded that external fixation is a satisfactory treatment method for tibial plafond fractures. Methodologic problems with this study include the timing of surgery in the ORIF group (average of 5 days) and the relatively underpowered study groups.

Yi-Chen Meng and colleagues conducted a meta-analysis based on observational studies comparing clinical outcomes of external fixation and open reduction and internal fixation of tibial pilon fractures (43A, 43B, and 43C according to AO/OTA classification). 11 eligible studies (10 cohort studies and 1 RCT: a total of 502 patients), published between 1993 and 2013, were used. The authors suggested that there is a relatively lower incidence of superficial infection, nonunion, and malunion in the ORIF group and higher rates of unplanned hardware removal. No significant difference was seen in deep infection, radiographic and clinical evaluation, posttraumatic arthrosis, or union time [45].

Anglen evaluated 63 patients that were treated with either hybrid external fixation or open reduction and plate fixation [46]. Patients were allocated to these treatment groups based on the status of their soft tissue status, fracture pattern, or systemic injury level. The author concluded that those patients with hybrid fixation had lower clinical scores, slower return to function, a higher rate of complications, more nonunions and malunions, and more infections. However, because of the preexisting treatment protocol, the study group allocation tended to result in a subjective distinction between the two groups with a greater proportion of pilons treated with hybrid external fixation to have more fracture comminution, greater soft tissue injuries, or more multisystem injury.

Pugh evaluated 60 patients with pilon fractures, and 21 were treated with an ankle-spanning half-pin external fixator, 15 with a single-ring hybrid fixator, and 24 with ORIF [47]. While no significant differences were noted between the external fixation group and the open plating group in overall complications, a greater number of malunions occurred in the fractures treated with external fixation when compared with ORIF. Four patients treated with hybrid fixators were left with angular deformities of greater than 5° (three varus, two valgus), and patients in the half-pin group demonstrated three varus and two articular malunions. There was one malunion in the ORIF group. The authors noted that if both groups of externally fixed fractures were compared with the ORIF group, fewer ($p = 0.03$) malunions in the ORIF group were noted. Also, the authors noted that the loss of the initial adequate reduction in the fixator groups was independent of bone grafting or fibular fixation.

Watson and colleagues developed a treatment protocol based on the severity of the soft tissue injury in 107 patients with tibial plafond fractures [48]. For all fracture types according to the AO/OTA classification, 81% of those treated with external fixation and 75% of those treated with open plating procedures had a good or excellent result. However, those with more severe fracture patterns (AO/OTA C-type), regardless of which treatment group they belonged to, demonstrated significantly poorer results than patients with type A or B fractures. In this study, patients with C-type fractures had higher rates of nonunion, malunion, and severe wound complications in the open plating group than those in the external fixation group. Of the 36 patients treated with ORIF, 5 (14%) had wound dehiscence or skin breakdown, which required 2 additional free flaps and 3 split-thickness skin graftings to resolve. Two of these developed osteomyelitis (5%). Comparatively, only two patients treated with external fixation had wound complications (4%), and neither of these required soft tissue coverage or skin grafting. There were no deep bone infections in the external fixation group. Late loss of reduction occurred in five patients with the subsequent development of nonunion in two (3%) and malunion in three (5%). Five additional patients had late loss of reduction, resulting in the development of nonunion in four (11%) patients and malunion in one (4%) patient. As in the previous studies, however, a predetermined treatment protocol results in groups that may be disparate in injury severity, and therefore rigid conclusions regarding treatment cannot be strongly made.

Blauth evaluated 51 patients over a 10-year span treated in 3 different ways: primary plate internal fixation, 1-stage articular ORIF with long-term transarticular external fixation for at least 4 weeks, and a 2-stage procedure with primary articular ORIF, short-term transarticular external fixation followed by secondary medial plate stabilization using limited skin incision technique [49]. Strong recommendations could not be made because of the limited number of patients within the groups and other methodologic problems, but the authors felt that the two-stage procedure provided the most satisfactory results.

Pollack performed a retrospective cohort analysis of pilon fractures treated at two level 1 trauma centers [6]. One center primarily treated tibial pilon fractures with ORIF and the other with external fixation with or without limited internal fixation. The purpose was to assess mid-term health, function, and impairment after pilon fractures and to examine patient, injury, and treatment characteristics that influence outcome. Eighty (78%) of 103 eligible patients were evaluated at a mean of 3.2 years after injury. General health, as measured with the Short Form-36 (SF-36), was significantly poorer than age- and gender-matched norms, with approximately 30–35% of patients reporting substantial ankle stiffness, persistent swelling, and ongoing pain. Of 65 participants who had been employed before the injury, 28 (43%) were unemployed at the time of follow-up, and 19 (68%) of these patients reported that the pilon fracture prevented them from working. Multivariate analyses revealed that presence of two or more comorbidities, being married, having an annual personal income of less than $25,000, not having attained a high school diploma, and having been treated with external fixation with or without limited internal fixation, was significantly related to poorer results as reflected by at least two of the five primary outcome measures. This comparative study demonstrated a number of interesting results including: (1) that a substantial amount of protracted disability persists after tibial pilon fracture, (2) many social variables that relate to functional and general health measures are out of the surgeon's control, and (3) the only injury or treatment characteristic that was significantly related to several of the selected outcomes was treatment method. After controlling for other patient and injury characteristics, participants treated with external fixation, with or without limited internal fixation, had more overall range-of-motion impairment and reported more pain and ambulatory dysfunction than did participants treated with ORIF. This study has arguably the highest quality of the retrospective comparative studies reviewed.

Koulouvaris used a case-control methodology to evaluate 55 patients with pilon fractures treated with 3 different techniques. There were 20 patients treated with half-pin ankle-spanning external fixation (Group A), 22 patients with ankle-sparing hybrid external fixation with limited arthrotomy (Group B), and 13 with 2-staged ORIF (Group C) [50]. The authors concluded that the hybrid group and the ORIF group were equally efficacious in achieving bone union but those with ankle-spanning external fixation had a significantly higher rate of delayed union and reduced activity level. Specifically, the mean time to union in Group A was 6.9 months as compared with 5.6 months in Group B ($p = 0.046$) and 5.1 months in Group C ($p = 0.013$). All patients united, though four patients in Group A required 11 months before union could be determined. Important complications that were evaluated included infections, advanced posttraumatic arthritis indicated for arthrodesis, and malunion. Four patients in Group A and two in Group B developed significant pin site infections requiring oral antibiotics, changes in pin site care, or pin removal. One patient in the ORIF group developed a deep infection requiring implant removal and conversion to external fixation. Six patients developed arthrosis changes for which arthrodesis was indicated, including four patients from Group A, one from Group B, and one from Group C. Six patients from Group A and one from Group B developed a malunion with between 5° and 10° of malalignment. One patient in Group C developed a varus malunion. Interestingly, all of the complications counted in the ORIF group (Group C) occurred in a single patient. The limited number of patients with complications precluded identification of significant differences between groups.

Wang most recently evaluated 56 closed B3- and C-type tibial pilon fractures randomized to either 2-stage ORIF (27 patients) or limited incision and external fixation (29 patients) [51]. Two wound infections and one pin-tract infection were identified in the ORIF group; no wound infections or 12 pin-tract infections were observed in the limited incision and external fixation group. All infections were successfully treated after intravenous antibiotic therapy except a wound infection in the ORIF group that required operative debridement. The incidence of superficial soft tissue infection (involved in wound infection or pin-tract infection) in the ORIF group was significantly lower than that in the external fixation group ($p < 0.05$). The external fixation group had higher rates of malunion, delayed union, and arthritis symptoms, but no statistical significance was demonstrated. Both groups resulted in similar ankle joint function, as measured with the modified Mazur ankle score. Logistic regression analysis, however, indicated that smoking ($p = 0.004$), increasingly severe fracture pattern ($p = 0.006$), and age ($p = 0.026$) were the factors significantly influencing the final outcomes.

A retrospective case series study was conducted by Davidovitch and associates comparing internal fixation, limited fixation, and external fixation of high-energy pilon fractures (OTA 43C). This study included 47 type 43C (comminuted intra-articular) fractures which were followed for a mean period of 18–20 months. Twenty patients with 21 fractures were treated with external fixation, and 26 fractures were treated with ORIF. Few patients in ORIF group were temporarily spanned (18) and splinted (8) until surgery, and patient treatment was assigned in a nonrandomized manner. Postoperative ankle range-of-motion, SMFA, and AOFAS (American Orthopedic Foot and Ankle Society) scores were obtained at each follow-up. Radiographic evidence showed degenerative arthritis in 81% of patients in the EF group compared to 73% in ORIF group. There were no significant differences noted in superficial and deep infections and nonunion or delayed union/malunion rates between the two groups. There was no difference in ankle range of motion and AOFAS. SMFA scores in the ORIF group were 34.3 compared to the EF group 25.8 [52].

Cisneros and associates comparing hybrid external fixation and stage management found mean time to radiographic union to be 133.82 ± 37.83 days versus 152.8 ± 72.33 days ($p = 0.560$), respectively. Ninety-three percent (12/13) in the hybrid fixation group united without any further surgery compared to all healing without further treatment in the staged management group. In regard to wounds and wound infection, three cases in the hybrid fixation group had a late pin-tract infection compared to three cases of skin necrosis seen in the ORIF group [53].

When considered overall, there is no clear treatment that can be strongly recommended. External fixation appears to have less associated deep wound complication rates than ORIF but may be more prone to problems with union (nonunion, malunion) than ORIF. Pollak's well-done retrospective study, however, suggests a treatment advantage of ORIF over external fixation when general health, functional outcome, and pain assessments are considered and also illustrates that a number of variables that are important to the final outcome are outside the control of the surgeon, including the degree of fracture comminution.

Importance of Articular Reduction

The attainment of an anatomic articular reduction is, perhaps, the most fundamental treatment philosophy of ORIF of periarticular fractures.

Proponents of ORIF, therefore, strongly link the ability to obtain and maintain an anatomic articular reduction with the best outcome possible, including functional outcome and minimization of arthrosis and the subsequent need for arthrodesis. The data supporting this, however, are minimal [54]. Questions such as to what degree does an articular surface need to be reduced, how can one accurately assess the amount of displacement after reduction and internal fixation, and how to account for difficult-to-measure biologic differences between individuals with seemingly similar injuries remain unanswered.

Literature Inconsistencies

The currently available literature remains suboptimal as a guide for the treatment of tibial pilon fractures, as the majority of this evidence is provided in the form of small retrospective cohort studies. While large-scale prospective randomized trials are ideal, this level 1 evidence will remain elusive. The myriad of potential fracture patterns and soft tissue injuries, the difficulties in assessing the accuracy of fracture reduction, and the impact which articular surface reduction has on functional outcomes are fundamental questions that still remain unanswered. Without understanding how the interaction and degree of importance that these variables have on outcome, determining the ideal treatment will remain ambiguous. What has become increasingly apparent, however, is that fractures of the tibial plafond have a substantial detrimental effect on function and quality of life and that patient factors out of the surgeon's control (socioeconomic variables) have a substantial impact on the outcomes of these injuries.

Evidentiary Table and Selection of Treatment Method

The key studies in treating JA are noted in Table 24.1 [6, 18, 20, 21, 28]. Based on the literature, the author recommends that the best treatment in this case would be ORIF done in a staged

Table 24.1 Evidentiary table: A summary of the quality of evidence for staged ORIF of tibial pilon fractures

Author (year)	Description	Summary of results	Level of evidence
Sirkin, Sanders, et al. (1999) [20]	Retrospective cohort study	48 pilon fractures treated with staged protocol, 19 of which were open. Overall deep wound infection rate of 6.3%	IV
Patterson et al. (1999) [21]	Retrospective cohort study	22 C3 pilon fractures treated with staged protocol. No infections or soft tissue complications; 9% arthrodesis rate at approximately 2 years	IV
Pollak et al. (2003) [6]	Retrospective comparative study	80 patients treated with either staged ORIF or external fixation followed for a mean of 3.2 years. Significantly poorer general health and functional outcomes than age and gender-matched controls. A number of social variables and the use of external fixation were associated with poor results	III
Boraiah et al. (2010) [28]	Retrospective cohort study	59 patients with open pilon fractures treated with staged ORIF demonstrated deep wound infection rate of 3%. Ten percent required bone grafting to achieve union	IV
Tang et al. (2014) [18]	Retrospective comparative study	46 patients with early fixation had a significantly shorter mean time to fracture union (21.5 ± 4 weeks vs. 23.3 ± 3.7 weeks, $p < 0.05$) and hospital stay (7.6 ± 2.6 days vs. 15.2 ± 4.2 days, $p < 0.01$)	III

fashion. This patient has substantial articular injury that is best reduced with open visualization, direct reduction, and rigid internal fixation using the principles espoused by Ruedi. The benefits of external fixation or percutaneous plating are minimized because of the lack of significant metadiaphyseal fracture extension. While the evidence that an accurate articular reduction fails to be strongly correlated with improved outcomes (using currently available functional assessments and outcome measures), the author strongly believes that an accurate articular reduction creates the optimal environment for joint preservation and function [55–57]. Ultimately, further research is needed to identify the degree to which this affects (or optimizes) patient outcomes within the confines of their injury severity.

Predicting Outcomes

The best intermediate- to long-term outcome data available for the management of tibial pilon fractures demonstrate a substantial amount of residual disability and interference with normal life activities. Ruedi's initial study fully followed 78 of the 84 pilon fractures treated with ORIF at a mean of 50 months. Seventy-four percent of these demonstrated good or excellent results. Of the original 84 fractures, 7 patients had had an arthrodesis (8%). They noted that most who developed arthrosis had symptoms early (<1 year), while the remainder tended to improve with time. Fifty-four of these fractures were rereviewed an average of 9 years after their injury [58]. The majority indicated they had no change in their symptoms, 12 improved, and 5 worsened. No further arthrodeses were noted. The authors concluded that a well-reduced tibial plafond fracture improves with time, that posttraumatic arthrosis of the ankle manifests itself within 1–2 years post-injury, and that a good result at the 1-year mark is generally maintained.

Teeny and Wiss would identify strikingly poorer results with higher-energy urban axial loading tibial plafond fractures with ankle fusion rates approximating 25% in comminuted Ruedi/Allgower type III injuries [16]. Fifty percent of their patients were rated as having a poor clinical result; the degree of comminution correlated with the clinical result. The quality of reduction was also closely correlated to the result; but untangling the degree of comminution with imperfect reductions complicates the determination of the relative importance of these variables with the outcome. The development of an infection greatly compromises the ability to obtain a reasonably satisfactory result, causing the authors to conclude that if anatomic reduction without soft tissue complications cannot be predicted preoperatively, consideration should be given to alternative types of treatment.

The last decade has seen an improvement in outcomes data with the use of validated, patient-specific outcome tools. To evaluate the intermediate term results of tibial plafond fractures, Marsh reviewed 56 pilon fractures treated with external fixation and limited incision articular fixation [59]. Thirty-five of these fractures were evaluated between 5 and 12 years post-injury. Five of 40 ankles had undergone arthrodesis (12.5%). There was a long-term negative effect on the SF-36 and Ankle Osteoarthritis Scale compared with age- and gender-matched controls. Ninety-one percent had X-ray evidence of arthrosis including osteophytes, joint space narrowing, or complete loss of joint space. Eighty-seven percent of patients were unable to run. Approximately 50% rated their ankle as excellent. Injury severity and reduction quality correlated with arthrosis, but the presence of arthrosis had only weak correlations with functional outcomes. Importantly, patients felt that they improved up to 2.4 years post-injury.

Pollak reviewed 80 patients treated with either external fixation or ORIF at a mean follow-up of 3.2 years [6]. General health as per SF-36 was significantly poorer than age- and gender-matched controls. Thirty-three percent of patients had ongoing pain. The use of external fixation and social factors (annual income < $25,000 and a lack of a high school diploma) were associated with poorer outcomes. Sixty-eight percent reported that their fracture prevented them from working.

Molina and associates, looking at 355 pilon fractures found that open fractures (33/59,

$p = 0.01$), hypertension (20/76, $p = 0.01$), and male gender (40/193, $p = 0.01$) were all risk factors for deep infection after operative treatment of type C pilon fractures [60].

When looking at the outcomes of soft tissue, there are many factors that are involved. With already compromised soft tissue, handling of the soft tissue during surgery can affect outcome. He and associates found that the "no touch" technique during the anterolateral approach (no retraction of the soft tissues with the exception of initial placement of the K-wires) was very effective in treating pilon fractures while minimizing complications. This study on 36 complex pilon fractures only had 1 superficial infection and 1 deep infection [61].

Williams evaluated 32 fractures treated with ankle-spanning external fixation and limited ORIF [62]. Patients were significantly lower in all but two SF-36 categories compared with age- and gender-matched controls. Similar to Marsh's study, radiographic arthrosis correlated with injury severity of the articular surface and the quality of reduction, but clinical ankle scores and the SF-36 correlated with preexisting patients variables, such as gender, level of education, and the presence of a work-related injury.

White and colleagues evaluated 95 fractures treated with acute ORIF [19]. At 1-year follow-up, the authors reported 6% with delayed healing unions or nonunions and a 1% arthrodesis rate. The SF-36 also demonstrated decreased physical and mental function compared with controls. Only 9% of patients reported no pain, with 85% reporting mild or moderate pain. Forty-four percent of patients had limitations in their recreational activities. Seventy-seven percent were restricted in either their recreational activities or their activities of daily living. Fifty-four percent had employment changes including loss of job, change to a lighter duty job, or required permanent injury benefits. Despite 90% of the initial reductions reported as anatomic, 78% had some evidence of arthrosis on 1-year follow-up radiographs.

Most recently, Jansen and associates, studying 35 patients and looking at the clinical outcome and gait pattern after pilon fractures, found that at a mean follow-up of 50 months, mean AOFAS, VAS foot and ankle, and Phillips scores were 65, 63, and 55, respectively. There were clear correlations between fracture severity and functional outcomes. There was also a clear correlation (0.74, $p < 0.01$) between the severity of the injury in the AO classification and the onset of posttraumatic arthrosis. Dynamic pedography revealed lesser load bearing for the total foot, medial foot, heel, and first metatarsal and medial forefoot for the affected limb. Increased load bearing was also seen in the lateral midfoot region [63].

In summary, tibial pilon fractures have long-term effects on physical and mental function as determined using patient-oriented functional and general health measurement tools. This translates into significant detrimental effects on patients' recreation, activities of daily living, and employment. Many of these outcomes are driven by preexisting social factors such as level of education, gender, and the presence of a work-related injury and degree of injury severity (such as fracture comminution), rather than the specific surgical interventions. Unfortunately, factors that are under the surgeon's control, such as quality of reduction and method of stabilization, are not yet strongly correlated with the final outcome and require further quality research to assess their impact, both at the clinical and basic science levels [46]. It is likely that a slow improvement occurs over the first 2–3 years, reaching a plateau at that time. The arthrodesis rate within the first 10 years is likely 7–12%, but outcomes beyond this time frame are largely unknown.

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Trimalleolar Ankle Fractures

25

Conor Kleweno and Edward K. Rodriguez

AG: A 30-Year-Old Female with Ankle Pain

Case Presentation

AG is a 30-year-old female who presents to the emergency department with a chief complaint of right ankle pain after "twisting" her right ankle while stepping off a curb and feeling a "pop." She denies any other injuries or pain and is unable to bear any weight on her right lower extremity. On primary survey, she demonstrates a GCS of 15 and a patent airway and is hemodynamically stable. On secondary survey, swelling and tenderness are noted in her right lower extremity, but no open wounds. Her past medical history is negative; she takes no medications and has no allergies.

C. Kleweno
Harborview Medical Center,
Department of Orthopedic Surgery,
Seattle, WA, USA

University of Washington,
Department of Orthopedics and Sports Medicine,
Seattle, WA, USA

E. K. Rodriguez (✉)
Beth Israel Deaconess Medical Center,
Department of Orthopedic Surgery,
Boston, MA, USA

Harvard Medical School, Boston, MA, USA
e-mail: ekrodrig@bidmc.harvard.edu

Physical examination demonstrates a healthy appearing female in no acute distress. Examination of her right ankle demonstrates no gross deformity to the right ankle, but edema is noted. No open wounds are present. The dorsalis pedis and posterior tibialis pulses are palpable and equal to the contralateral extremity. Sensation to light touch is intact in all dermatomal distributions, and leg and foot compartments are soft and compressible. Ecchymosis is noted around the ankle. The patient is able to move all of her toes in plantar and dorsiflexion. No pain or deformity is noted in the knee or proximal leg. Radiographs of the right ankle pre- and postreduction are demonstrated in Figs. 25.1a–c and 25.2a–c.

Interpretation of Clinical Presentation

The history and physical exam describe a healthy 30-year-old female with an isolated, low-energy injury to her right ankle. Once severe soft tissue injury or an open fracture or dislocation is evaluated by visual inspection, radiographs should be obtained of her ankle. In general, pain and inability to bear weight should prompt the clinician to consider obtaining X-rays of the ankle, including AP, lateral, and mortise views. In a prospective study, Stiell and associates [1] introduced the Ottawa ankle rules that recommend ankle radiographs be obtained on patients presenting to the emergency room with ankle pain if they report

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Fig. 25.1 (**a**) AP radiograph of the ankle (**b**) Mortise radiograph of the ankle (**c**) Lateral radiograph of the ankle

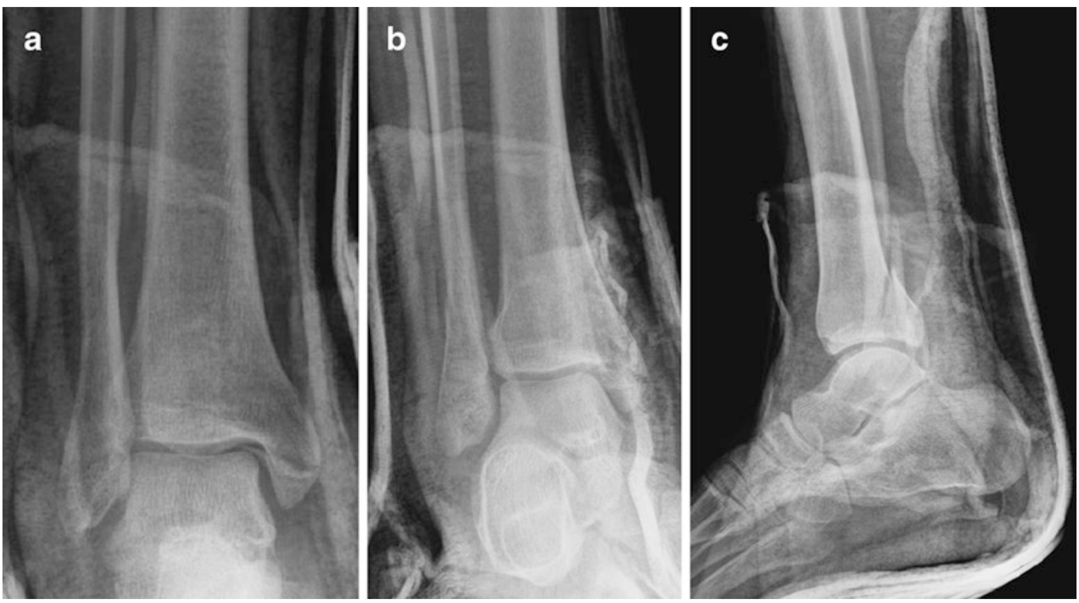

Fig. 25.2 (**a**) Postreduction AP radiograph of the ankle (**b**) Postreduction mortise radiograph of the ankle (**c**) Postreduction lateral radiograph of the ankle

malleolar pain and one of the following additional criteria: age over 55, medial malleolar tenderness, lateral malleolar tenderness, or inability to ambulate. These criteria led to 100% sensitivity and 40% specificity in a cohort of 689 patients with 70 ankle fractures. Pigman and associates [2] independently evaluated the Ottawa rules in 110 emergency room patients and again found a sensitivity of 100% but a specificity of 19%.

Physical examination of the knee should be performed, and knee X-rays should be considered if any proximal fibular tenderness is present to evaluate for a fracture of the proximal fibula ("Maisonneuve" fracture), suggesting the presence of syndesmotic disruption. Hanson and associates [3] published a case report of an unstable syndesmotic ankle injury, with initial ankle films showing a small medial malleolar avulsion fracture and small posterior malleolar fracture (15%), but with normal talar alignment. Knee films revealed a proximal fibular fracture, and fluoroscopic stress testing demonstrated syndesmotic widening and lateral talar shift indicating an unstable ankle that thus underwent surgical fixation.

Initial radiographic images of patient AG's ankle reveal a trimalleolar ankle fracture with initial posterior dislocation of the talus. A trimalleolar fracture can be defined as a fracture of the ankle that involves the lateral malleolus, the medial malleolus, and the distal posterior aspect of the tibial articular surface, which although a misnomer can be termed the "posterior malleolus". The posterior malleolar fracture fragment results from avulsion by the posterior-inferior tibiofibular ligament (PITFL) at its site of attachment to the tibia as part of a rotational injury (in contrast to the axial load pattern observed in a pilon-type distal tibia fracture).

Given the patient's dislocation seen on initial radiographs, there is a clinical indication for her to undergo initial closed reduction. Primary reasons for initial reduction are to protect the overlying skin from a tension injury, as well as to restore articular alignment and reduce the risk of vascular compromise and ischemia. Special attention should be paid to the soft tissues to evaluate for any skin that is ischemic or threatened due to tenting over bony prominences. In this situation, with a tibiotalar dislocation, closed reduction should be performed as expeditiously as possible. Alioto and associates [4] reported 0% complication rate in their study of 23 patients who underwent tibiotalar joint hematoma block injection using 2% lidocaine without epinephrine (no adverse drug reactions, no lidocaine toxicity, no infections, and no nerve injuries). A closed reduction can also be performed with conscious sedation supplementation depending on the emergency medicine or anesthesia staff available.

By standard of care, patients are then placed in a well-padded splint or cast molded to hold the reduction. Postreduction films are obtained to verify reduction. The injured ankle should be initially elevated as much as possible, regardless of treatment plan, to help minimize soft tissue swelling. Ankle fractures that include a posterior malleolar fragment have a greater risk of recurrent talar dislocation posteriorly. This posterior instability can lead to re-dislocation or subluxation after closed reduction, so close monitoring while awaiting definitive care is warranted. Plantar flexion of the ankle to decrease the tension of the gastroc-soleus complex, as well as adding an anterior-posterior mold to the splint, can help prevent this. Fig. 25.2a–c demonstrates that the ankle joint has been reduced. However, there remains ~2–3 mm of articular incongruence on the lateral X-ray.

When the size of the posterior distal tibial fracture fragment ("posterior malleolus") is potentially large enough to fix (see discussion below), a computed tomography (CT) scan should be considered to better characterize the size and geometry of the fragment. Ferries and associates [5] evaluated 25 trimalleolar ankle fractures with both plain radiography and CT scanning and found that over half (54%) of plain radiographs had >25% error in estimating size. The geometry pattern of the posterior fracture is variable but important for preoperative planning and best visualized on CT scan. In a study by Haraguchi and associates [6], CT scans were obtained in 57 ankle fractures containing a posterior malleolar fragment, and the angle between the bimalleolar axis and the major fracture line of the posterior malleolus ranged from 9° to 40°. In addition, these authors found that this fracture line did not correspond well with standard radiographic positions.

Declaration of Specific Diagnosis

AG is a 30-year-old female who presents with a low-energy injury that consists of an initially dislocated closed trimalleolar ankle fracture status post closed reduction.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Maintain concentric reduction of the ankle joint mortise.
2. Prevent ankle joint arthrosis.
3. Allow early mobilization of the patient.
4. Regain motion after fracture healing.
5. Eventual return to normal life activities.

Treatment options include:

Conservative/non-operative treatment:

1. Casting

Operative treatment:

1. External fixation
2. Plate fixation (posterior malleolus)
3. Lag screws (posterior malleolus)

Evaluation of the Literature

A literature search on trimalleolar ankle fractures was performed using Medline and PubMed databases. Keywords included the following: "ankle fracture," "trimalleolar ankle," "posterior malleolus," and "trimalleolar ankle fracture." From this search, relevant articles were identified, and reference lists were reviewed. The PubMed search included articles until 2017. Earlier studies and clinical reports were included for historical context and when there was lack of more recent data.

Detailed Review of Pertinent Articles

Conservative/Non-operative Treatment

Bauer and associates [7] reported an average of 7-year follow-up for 92 patients with ankle fractures in a randomized controlled trial of operative vs. non-operative treatment and found comparable results between the two treatments in terms of subjective symptoms, range of motion, and rate of arthrosis (72% operative vs. 65% non-operative). Of note, this study included uni-, bi-, and trimalleolar ankle fractures. There were 19 trimalleolar fractures in the operative group and 14 trimalleolar fractures in the non-operative group, with no significant difference in outcomes found between these in subgroup analysis.

In addition, an early report by Harper and Hardin [8] found no difference in clinical outcomes (e.g., pain, range of motion, presence of limp), quality of radiographic reduction, and arthrosis of 15 patients treated surgically and 23 patients treated non-operatively with trimalleolar ankle fractures of at least 25% of the posterior malleolus (based on lateral X-ray) with 44-month average follow-up. Interestingly, these authors also reported no residual posterior talar subluxation, noting that posterior malleolar reduction was achieved after fibular reduction and fixation.

In patients in whom surgical risk is too high and the soft tissue is appropriate, casting is a reasonable option and has the potential for satisfactory outcomes given the maintenance of reduction. Early and frequent follow-up with repeat imaging is necessary to ensure that the talus is not subluxated posteriorly. Loss of fixation and skin breakdown are known potential complications. For example, Phillips and associates [9] reported 2 pressure sores and 1 loss of reduction in a cohort of 49 bimalleolar ankle fractures managed with closed reduction and casting. Additionally, Bauer and associates [7] reported 8 of 57 ankle fracture patients initially treated with closed reduction and casting had loss of reduction requiring operative fixation (3 lateral malleolar, 1 bimalleolar, and 4 trimalleolar).

Operative Treatment

Surgical Indications

Identifying the indications for surgical fixation of the posterior malleolar fragment is one main controversy regarding the surgical management of trimalleolar ankle fractures and is what we will focus on in this review. In a recent large survey of 400 orthopedic surgeons, significant variation was observed in treatment indications and treatment strategies for posterior malleolar fractures [10].

Historically, the indication for fixation was based on size of the fragment, referenced as the percentage of the distal tibial articular surface measured on the lateral ankle radiograph or CT. The concept here is that presence of a sufficiently large fragment will lead to posterior talar instability with subluxation (and possibly dislocation). There are various biomechanical and clinical studies evaluating this issue in an attempt to quantify the critical size of the posterior malleolar fragment that requires fixation. However, the exact size of the fragment to cause significant instability remains unclear, and surgeon opinion on essential size varies [10].

Moreover, it has recently been increasingly recognized that fixation of the posterior malleolus has significant effect on reduction and stability of the syndesmosis [11].

Macko and colleagues [12] performed biomechanical testing on eight cadaveric ankles, evaluating reduction in joint contact area with posterior malleolar fractures, and noted a significant reduction with 33% size fragments with a maximum loss of contact area with 50% sized posterior malleolar fractures. In a separate cadaveric study, Hartford and colleagues [13] created posterior malleolar fragments of 25%, 33%, and 50% and under neutral flexion loading found decreases in tibiotalar contact area of 4%, 13%, and 22%, respectively. These authors concluded that only the fragments ≥33% lead to a significant decrease in tibiotalar contact area.

The presumption from these studies is that reduced articular congruency (and thus decreased joint contact area) results in increased joint contact stresses and that this in turn leads to degenerative damage to the articular cartilage and thus future symptomatic arthrosis. However, the true cause of post-traumatic arthrosis is not certain. Fitzpatrick and colleagues [14] used a cadaveric model to evaluate tibiotalar contact stresses by dynamically loading ankles that were intact compared with four fracture simulations (50% fracture without internal fixation, 50% fracture fixed with 2-mm gap malreduction, 50% fracture fixed with 2-mm step malreduction, and 50% fracture fixed anatomically). Interestingly, the authors measured no talar subluxation and no increase in contact stresses near the articular fracture. The predominant area of stress was central in intact ankles and shifted anterior and medial in fracture models. The authors concluded that this shift in cartilage loading might be the causative factor in post-traumatic arthritis. This study was limited by modeling an isolated posterior malleolar fracture (a rare occurrence) without concomitant bimalleolar fractures and soft tissue injury.

Raasch and colleagues [15] conducted a cadaveric study evaluating posterior instability of the talus, where no instability (less than 1-mm posterior translation) was found after removing up to 40% of the posterolateral articular surface. However, these authors further demonstrated that with additional sectioning of the anterior tibiofibular ligament and fibula (simulating a more clinically realistic situation), instability occurred with the removal of 30% of the posterolateral articular surface. In a separate cadaveric study, excessive internal rotation and posterior instability were found by Scheidt and colleagues [16] who analyzed posterior malleolar fractures in conjunction with a posterior tibiofibular ligament complex of only 25% size.

Early clinical reports suggested fixation for fragments representing a range of 25–33% of the articular surface as measured on the lateral radiograph [17, 18]. McDaniel and Wilson [19] concluded that fixation of fragments 25% or greater leads to better results than closed management, although this was based on only 15 patients with posterior fragments of that size.

In addition to the size of the fragment, the reestablishment of articular congruence (regardless of treatment method) is essential. Recently, Langenhuijsen and colleagues [20] retrospectively evaluated outcomes of 57 trimalleolar ankle fractures and found that joint incongruity (≥1 mm) was the main prognostic factor. They recommended joint congruency should be obtained for any fragment ≥10% (either held with internal fixation or closed reduction). Note that these studies are all limited by relying on lateral radiographs to determine fragment size.

Given this variation in biomechanical and clinical data, there is no definitive size of a posterior malleolar fracture fragment requiring open reduction and internal fixation, although a size of at least 25% can be considered clinically important for consideration based upon both the clinical and biomechanical data. As discussed above, the determination of size is best estimated by CT scan. Additionally, surgical indications based on the current literature include any residual posterior subluxation or dislocation of the talus and articular incongruence (>1 mm) after closed reduction.

Lastly, the concept of improving stability of the syndesmosis by fixation of the posterior malleolus regardless of size is increasing in popularity. Fixation of the posterior malleolar fragment has been associated with reestablishment of syndesmotic stability. Anatomically, in an ankle injury with a rotational component, fractures through the posterior tibia imply an intact PITFL, and thus fixation of this fragment theoretically improves stability. In a cadaveric study, Gardner and colleagues [11] found that posterior malleolar fixation alone provided improved stability compared with a typical syndesmotic screw fixation (single 3.5-mm tricortical screw) (70% vs. 40% of intact specimens, respectively). Thus, for example, even small fragments might be considered for surgical fixation to enhance stability.

In our patient AG, there were initial posterior dislocation of the talus, a posterior malleolar fracture size of ~33% based on the lateral X-ray, and ~2–3 mm of joint incongruity after closed reduction, and thus we recommend surgical fixation.

External Fixation

External fixation is an option for temporary or definitive fixation. In patients who have significant soft tissue swelling or have sustained additional polytrauma making them too physiologically unstable to undergo acute surgical care, external fixation offers stabilization of the fracture and soft tissue envelope. Even if for temporary treatment, the external fixator should be assembled so that the ankle joint is out to length to prevent soft tissue contracture. Neutral flexion can be achieved with forefoot pins in the cuneiform or metatarsal bones and will limit plantar flexion contracture.

For certain patients, external fixation can be used for definitive treatment. This includes patients whose soft tissue is severely tenuous or damaged or patients with extreme fracture comminution. Unfortunately, there is an absence of outcome studies of external fixator treatment for trimalleolar fractures.

Plating vs. Screws

The fibula and medial malleolus should be fixed according to surgeon preference, and controversies regarding this are beyond the scope of this review. We will instead focus on fixation of the posterior malleolar fragment.

There remains controversy regarding the optimal treatment strategy for the posterior malleolar fragment. The two most commonly used options include independent screws placed anterior to posterior (AP) alone versus posterior antiglide plating.

Screws

The first common method of posterior malleolar fracture fixation is with interfragmentary lag screws. Often, the posterior malleolar fragment partially reduces when the lateral malleolus is reduced because of the attachment to the PITFL. Further anatomic reduction can be accomplished percutaneously with a large pointed reduction clamp and then fixed with one or two screws placed from anterior to posterior (AP) or (less commonly) posterior to anterior. One can choose partially threaded cancellous lag screws (lag by design), fully threaded cortical screws (lag by technique), or a combination of the two. When placing a lag by design screw from anterior to posterior, care should be taken to avoid having threads across the fracture plane and negating the lag screw compression effect. Indirect reduction and percutaneous AP lag screw fixation were the traditional AO/ASIF recommendation [20].

Plating

Open reduction and placement of an antiglide plate are a second option. There has been a trend toward direct exposure and posterior plating of the posterior malleolus becoming more popular, compared with traditional percutaneous AP screw fixation.

One primary reason for open reduction is potentially improved restoration of articular congruence. The intra-articular reduction of the posterior malleolar fragment can be determined indirectly by fluoroscopy and direct visualization of the extra-articular fracture line. The intra-articular aspect is difficult to visualize due to overhang of the posterior tibia, but the fracture line can be cleaned out sufficiently for anatomic reduction. Dorsiflexion of the ankle may aid in reduction due to attachments of the posterior capsule and posterior tibiofibular ligament. However, the dorsiflexion might also lead to posterior translation of the talus, and an anteriorly directed force may be required concomitantly. A large pointed clamp can be placed between the fracture fragment and the anterior distal tibia to hold reduction, and small K-wires can also be used for provisional fixation. Once reduction is obtained, an antiglide plate is applied. This plate can be selected based on the size of the fragment and can be a simple 1/3 semitubular plate or a more custom plate as needed. Some manufacturers are presently marketing pre-contoured plates for this application.

Recent clinical data support plate usage. Huber and colleagues [21] compared the quality of reduction radiographically in 60 ankle fracture dislocations with involvement of the posterior malleolus. Thirty patients were treated with a single posterolateral approach, direct open reduction, and dorsal antiglide plate fixation, and 30 patients were treated with indirect reduction and anteroposterior screws. Anatomical reduction of the posterior malleolus was more frequent with direct reduction and plating (25/30, 83% of cases) compared with indirect reduction and screws (8/30, 27% of cases). Follow-up was at least 1 year in all patients, and there were no differences in postoperative complication rate. However, the authors acknowledged that follow-up was not long enough to determine if there was a difference in the eventual development of osteoarthrosis between the two groups. O'Connor and colleagues [22] reported a small retrospective clinical study (27 total patients) comparing AP screws to posterior plating with the plating group having improved clinical outcome scores at 1 year. No loss of reduction, however, was seen in either group. Although AP screws are most common, independent posterior-to-anterior (PA) screws can also be placed through a posterolateral approach. Erdem and colleagues [23] found no difference in clinical and radiographic outcomes between PA screws and posterior buttress plating in a prospective case series of 40 patients.

Recent biomechanical studies also support posterior plating. A cadaveric study with a 30% posterior malleolus model compared AP screws to a posterior one-third tubular plate (without lag screws) and found significantly less displacement in the plate model, indicating biomechanical superiority for a buttress plate [24]. This conclusion was supported by Hartwich and colleagues [25] who utilized an osteoporotic pronation abduction ankle fracture with posterior tibial fragment model comparing AP screws to posterior plating, again measuring higher biomechanical stability with the posterior plate.

Posterior buttress plating is not without risk. Careful surgical technique is necessary to avoid risk to the flexor hallucis longus muscle, peroneal artery, and sural nerve. In addition, anterior structures can also be at risk. A recent cadaveric study noted particular risk to the tibialis anterior tendon with over-penetration of anterior cortex when placing provisional and definitive fixation [26].

A second consideration of plating is that the same skin incision can be utilized for both fixation of the fibula with a posterior plate and plating the posterior tibia via a posterolateral exposure. Reducing and plating the fibula fracture first will bring the ankle out to the appropriate length and, as Harper and Hardin [8] noted, may also reduce the posterior malleolar fragment. After fibular fixation, one can dissect along the plane between the peroneal tendons and the FHL to reach the posterior surface of the tibia. One technical note is that fibular plating can obscure the view of the posterior tibia and provisional fixation of the fibula prior to plating might allow improved radiographic evaluation of the posterior malleolar reduction.

Tornetta and coworkers [27] reported results on 63 ankle fracture patients who underwent posterolateral plating of a posterior malleolar fragment with overall excellent results with no loss of reduction and no deep infections, providing data to support the plating technique. The authors state that advantages include direct visualization of fracture, direct application of plates for reduction, and simultaneous reduction and fixation of the lateral malleolus through the same skin incision. However, they did have six patients with wound erythema treated with oral antibiotics, seven patients who developed some degree of skin edge necrosis (all healed with local wound care), four patients with sural nerve numbness (three out of four resolved), and one fibular nonunion. More recently, Verhage and coworkers [28] reported on 52 patients treated with posterolateral approach and plating with anatomical reduction in all patients with only one superficial wound infection.

Postoperative Care

There is currently disagreement in terms of duration of protected weight bearing after ankle fractures in general (including trimalleolar fractures). A large survey among orthopedic surgeons (>700) found significant variation in recommended non-weight bearing after fixation of ankle fractures from ~4 to 8 weeks [29]. The authors noted both injury pattern and medical comorbidity contributing to the decision. Many treating surgeons do not prescribe full weight bearing until union is solid, and this may require 3 months or longer. However, Papachristou and coworkers [30] allowed early full weight bearing after open reduction and internal fixation in a cohort of trimalleolar fractures and found no complications, although there were only 15 patients in the group. Regardless of weight-bearing status, patients should be transitioned from their postoperative splint to a functional brace (e.g., Aircast boot, walking boot) with range of motion exercises started soon after surgery. Egol and coworkers [31] randomized two groups of postoperative ankle fracture patients to functional bracing and early range of motion compared to casting for 6 weeks. These authors found significantly earlier return to work in the functional bracing group and improved early functional outcomes (although in 1-year follow-up the functional scores were similar between groups). The decision to prescribe a dedicated physical therapy or specific exercise program after ankle fracture surgery should be based on individual patient needs. A large randomized clinical trial compared a physical therapist-supervised exercise program and advice about self-management and rehabilitation or advice alone, and reported equivalent outcomes, thus not supporting routine prescription of physical therapy for uncomplicated, isolated ankle fractures [32].

Literature Inconsistencies

The lack of definitive evidence-based guidelines for optimal treatment of posterior malleolar fractures in association with trimalleolar fractures is due to the lack of randomized prospective controlled trials with long-term follow-up, including rates of post-traumatic osteoarthritis. There has been variation in the threshold for the size of the posterior malleolar fragment in both cadaver biomechanical studies and clinical outcome studies that indicate surgical stabilization has improved outcomes. This is partly due to variation in the manner of size determination (lateral plain film vs. CT scan). Additionally, there is lack of level I evidence to definitively support one particular method of fixation (plates vs. screws) although multiple studies have shown biomechanical superiority of plating. More prospective randomized data are needed.

Definitive Treatment Plan

Based on the literature and our treatment goals, we recommend surgical fixation of AG's fracture. In addition, we specifically recommend a posterolateral approach and placement of an antiglide plate to address the posterior malleolar fracture given that it offers improved anatomic reduction and biomechanical superiority.

Evidentiary Table and Selection of Treatment Method

The key studies in treating AG are noted in Table 25.1 [13, 15, 20–28]. Grading quality of evidence was based on Levels of Evidence for

Table 25.1 Evidentiary table: A summary of the quality of evidence for surgical fixation of posterior malleolar fractures

Author (year)	Description	Summary of results	Level of evidence
Bennett (2016) [24]	Basic science	14 cadaveric ankles with 30% posterior malleolus model compared AP screws to a posterior one-third tubular plate (without lag screws); significantly less displacement in the plate model, indicating biomechanical superiority for the buttress plate	N/A
Erdem (2014) [23]	Prospective case series	40 patients randomized to lag screw only vs. plate fixation of the posterior malleolus; equivalent functional and radiographic outcomes were observed	II
Hartford (1995) [13]	Basic science	16 cadaveric ankles loaded after creating posterior malleolar fractures and concluded that only the fragments ≥33% lead to a significant decrease in joint contact area	N/A
Hartwich (2017) [25]	Basic science	14 paired osteoporotic cadaver ankle fracture models loaded comparing AP lag screws to posterior antiglide plate; plate was mechanically more stable	N/A
Huber (1996) [21]	Prospective comparative	60 ankle fracture dislocations were treated with direct reduction and plating vs. percutaneous screws with superior anatomic reduction using plating	II
Karbassi (2016) [26]	Basic science	10 cadaveric ankles with posterior-to-anterior K-wires were advanced at varying levels above the articular surface; the tibialis anterior tendon was injured by 52% of all K-wires	IV
Langenhuijsen (2002) [20]	Retrospective cohort	57 patients with trimalleolar ankle fractures with an average follow-up of 6.9 years. Joint incongruity (≥1 mm) was the main prognostic factor for any fragment ≥10% (either held with internal fixation or closed reduction)	III
O'Connor (2015) [22]	Retrospective case series	27 patients followed comparing AP screws to posterior plating with the plating group having improved clinical outcome scores at 1 year	III
Raasch (1992) [15]	Basic science	7 cadaveric ankles loaded after creating posterior malleolar fractures and transecting anterior tibiofibular ligament and fibula. Instability occurred with the removal of 30% of the posterolateral articular surface	N/A
Tornetta (2011) [27]	Retrospective cohort	63 ankle fracture patients underwent posterolateral plating of a posterior malleolar fragment with overall excellent results with no loss of reduction	III
Verhage (2016) [28]	Retrospective cohort	52 ankle fracture patients underwent posterolateral plating with excellent reduction and minimal complications	III

Primary Research Question provided by the Journal of Bone and Joint Surgery as referenced on their website (http://www.jbjs.org/public/instructionsauthors.aspx#LevelsEvidence).

Predicting Outcomes

In general, reported outcomes of trimalleolar ankle fractures are worse than bimalleolar or isolated lateral malleolar ankle fractures. Jaskulka and coworkers [33] in a retrospective study compared 62 trimalleolar ankle fractures with 82 bimalleolar fractures at an average of 5.7-year follow-up. All lateral and medial malleolar components were surgically fixed, and in 14/62 trimalleolar fractures, the posterior malleolar fragments were also fixed (in patients with fragment size >20%). The authors reported worse results in terms of pain and function with the trimalleolar ankle fractures. In addition, they found a significantly higher rate of osteoarthrosis in the trimalleolar group, even for posterior lip avulsion fractures (fragment <5%). More recently, Verhage and coworkers [34] reported on 243 ankle fractures and observed development of osteoarthritis occurring predominantly in trimalleolar fractures.

In a large retrospective study of 57,183 patients after open reduction and internal fixation of a lateral malleolar, bimalleolar, or trimalleolar ankle fractures, SooHoo and coworkers [35] found a significantly higher rate of intermediate-term (1- and 5-year follow-up) rate of reoperation for ankle fusion or replacement in patients with trimalleolar fractures compared with isolated lateral malleolar fractures [1.21% vs. 0.64%; hazard ratio of 2.07 (95% confidence interval, 1.50–2.84; $p < 0.001$)].

McDaniel and Wilson [19] reported on the long-term results of 51 trimalleolar fractures, 28 treated closed and 23 treated operatively. At an average follow-up of 42 months, these authors found a higher incidence of post-traumatic arthritis and more overall poor results compared with historic bimalleolar controls. In addition, Tejwani and coworkers [36] compared 54 trimalleolar fractures (20 treated surgically) with 255 bimalleolar and unimalleolar ankle fractures and reported worse functional scores at 1-year follow-up for the trimalleolar group in terms of pain, the American Orthopedic Foot and Ankle Society (AOFAS) scoring system, and the Short Musculoskeletal Function Assessment (SMFA) scoring system. Interestingly, at 2-year follow-up, these differences were no longer significant. In slight contrast, De Vries and coworkers [37] found overall good clinical outcomes including pain scores, Ankle Fracture Scoring System (AFSS), and development of arthritis on 42 trimalleolar ankle fracture patients after a mean of 13-year follow-up (this cohort included a wide range of fragment size 3–49% and both fixated and non-fixated fragments), although the study was limited by small sample size. More recently, Hong and coworkers [38] reported on 31 operatively treated trimalleolar ankle fractures with the majority experiencing residual decreased function and limitations on return to sport at 1-year follow-up.

The size of the posterior fragment might predict outcome. In a recent retrospective study by Mingo-Robinet and coworkers [39] of 45 patients with trimalleolar fractures surgically fixed, the authors reported overall better outcomes in 20 patients whose fragment size was <25%, compared with 25 patients with fragment size >25%, although for the most part these data were trends and did not reach statistical significance. Similarly, a retrospective cohort study of 131 patients with trimalleolar ankle fractures (mean follow-up of 7 years) showed that medium- and large-sized fragments had more osteoarthritis than small-sized fragments [40].

The fact that there was an initial dislocation likely predicts a worse outcome for patient AG. De Vries and coworkers [37] reported worse clinical outcome scores (AFSS) and higher rates of osteoarthritis in 20 trimalleolar patients with an associated dislocation compared with 24 non-dislocated trimalleolar patients.

In terms of short-term complications of ankle fractures in general, a recent study of a large cohort of ankle fractures (>3000 patients) found that risk factors for 30-day postoperative complications included peripheral vascular disease, open injury, non-clean wound classification, age 70 years or older, and ASA classification ≥3 [41]. In addition, Miller and coworkers noted diabetes, peripheral neuropathy, wound-compromising medications, open fractures, and noncompliance as risk factors for wound complications in a cohort of 478 patients. Further, a large database analysis determined that ankle fracture patients with the combination of obesity and diabetes had higher health-care utilization and costs [42].

In general, the data suggest that achieving a congruent joint will optimize patient AG's outcomes, although she should be counseled that trimalleolar fractures tend to result in worse outcomes compared with uni- and bimalleolar fractures.

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Calcaneus Fractures

26

Richard Buckley and Theodoros H. Tosounidis

RF: A 22-Year-Old Male with Foot Pain

Case Presentation

RF is a 22-year-old male who presents to the emergency department with the chief complaint of left foot pain after being involved in a motor vehicle crash. He denies any other injuries or pain and is unable to bear any weight on his left lower extremity. He denies any loss of consciousness. On primary survey, he demonstrates a GCS of 15 and a patent airway and is hemodynamically stable. On secondary survey, no gross deformity is noted to his left lower extremity.

His past medical history is negative; he takes no medications and has no allergies. He reports that he works as a carpenter and smokes one pack per day.

Physical examination demonstrates severe pain with palpation to his left heel. There is ecchymosis, and moderate edema is noted. No open wounds are present. The dorsalis pedis is palpable. Sensation to light touch is intact in all dermatomal distributions of the foot. Compartments of the foot are soft and compressible. The patient is able to move all of his toes in plantar and dorsiflexion. No pain or deformity is noted in the knee or proximal leg.

Radiographs and CT scans demonstrate a displaced intra-articular calcaneus fracture (Figs. 26.1a, b and 26.2a–f).

Of note, the patient also sustained a medial malleolus fracture of the ankle which was treated with an ORIF during the initial hospital course. For purposes of this chapter, we will consider the calcaneus fracture an isolated injury.

Interpretation of Clinical Presentation

The history, the physical examination, and the diagnostic work-up reveal that the patient sustained an isolated calcaneus fracture.

Motor vehicle accidents account for almost 20% of calcaneal fractures. Work-related injuries and falls from a height contribute equally to the remaining 80% [1]. Young male patients, like the one in this case, suffer the vast majority of calcaneus fractures. The patient in this case is a heavy smoker (>20 cigarettes per day). Apart from awareness that smoking is a known risk factor for

R. Buckley (✉)
Department of Surgery, Foothill Medical Center, University of Calgary, Calgary, AB, Canada
e-mail: buckclin@ucalgary.ca

T. H. Tosounidis
Major Trauma Centre, Leeds General Infirmary, Academic Department of Trauma and Orthopedic Surgery, University of Leeds, NIHR Leeds Biomedical Research Unit, Chapel Allerton Hospital, Leeds, UK

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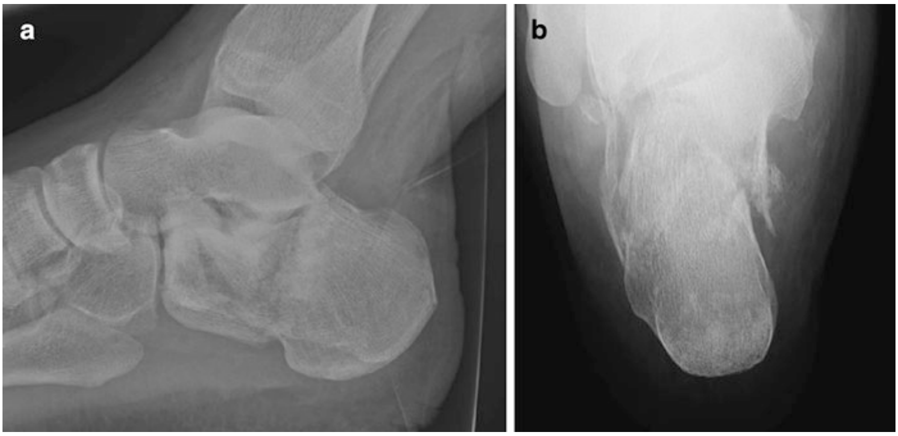

Fig. 26.1 (**a**) Lateral radiograph of the heel (**b**) Harris heel radiograph

impaired fracture healing, studies in the literature indicate that smoking may be a contraindication to surgical treatment due to the high rate of wound complications and up to 15% infection rate in smokers. These complications include local wound necrosis, wound slough, and infection both superficial and deep [2–4].

Since 20–60% of calcaneus fractures occur in the context of an additional injury or an ipsilateral fracture, an isolated calcaneus fracture always requires a thorough and detailed clinical examination. Special attention should be given to the lumbar spine and the contralateral calcaneus, as these are the most common associated injuries in approximately 10% of patients [1]. Consequently, the primary and secondary surveys, with strict adherence to ATLS protocol, are of paramount importance in the evaluation of a patient who has suffered a calcaneus fracture.

The clinical examination of the injured hindfoot demonstrates signs that are common with other hindfoot fractures: pain, intolerance to weight bearing, swelling, and tenderness. Increasing pain may mean the development of compartment syndrome of the foot. The largest series in the literature reported that only 2 out of the 459 studied calcaneal fractures developed an acute compartment syndrome, with 6% of patients showing the long-term sequelae of this syndrome (intrinsic toe flexion contractures) [5]. Additionally, blistering is a feature that is not present on the initial evaluation of this patient, but it should be kept in mind that blisters usually appear on the medial side, within 36 h of the injury. They can be hemorrhagic, and the presence indicates severe soft tissue injury that may delay surgical treatment of the patient.

Radiographs demonstrate a displaced intra-articular fracture. According to the Essex-Lopresti classification scheme, this fracture is classified as a "joint depression" type. Bohler's angle is 0° or less (angle of line from top of the calcaneal tuberosity to the back of the posterior facet and from the anterior calcaneus to the posterior facet). The hindfoot is not in excessive varus (as measured by a vertical line through the talus and through the middle of the calcaneus), and the calcaneal width is not increased significantly. Two-dimensional computed tomography (CT) images reveal a displaced (>2 mm) comminuted calcaneal fracture involving the posterior facet. According to the Sanders classification [6], this fracture can be categorized either as a type III or as type IV, depending on which coronal view of the posterior facet is used. Interpretation of the CT images uses the widest undersurface of the posterior facet of the talus as a coronal reference point in order to classify the fracture. The Sanders scheme is a useful classification that measures the number of posterior facet pieces at the level of the sustentaculum tali on the coronal CT image. When evaluating calcaneus fractures, the Sanders classification demonstrates moderate interobserver reliability [7].

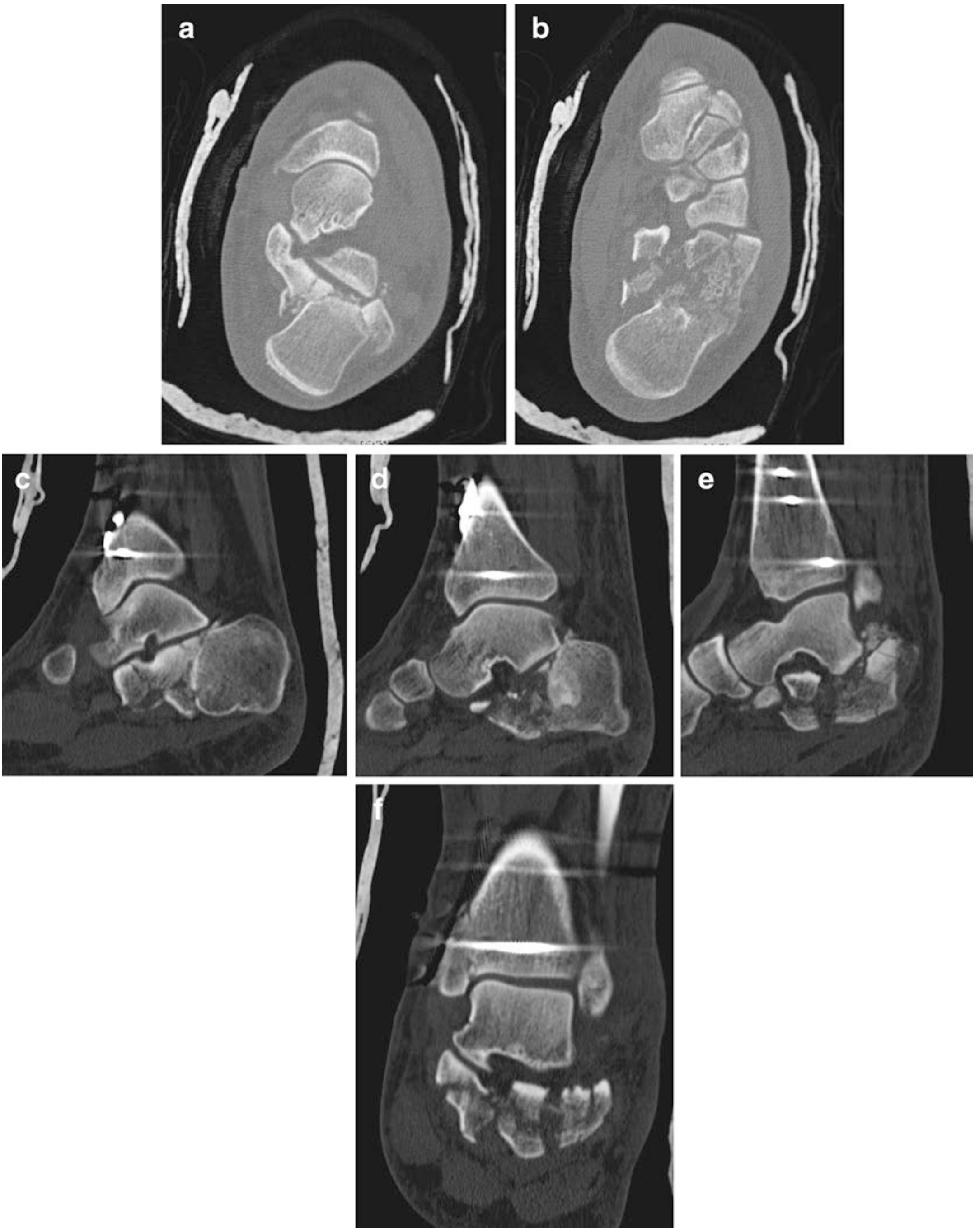

Fig. 26.2 (**a, b**) Axial CT of the calcaneus (**c–e**) Sagittal CT of the calcaneus (**f**) Coronal CT of the calcaneus

Declaration of Specific Diagnosis

RF is a 22-year-old male smoker involved in a motor vehicle collision with an isolated, closed, neurovascularly intact, displaced left intra-articular calcaneus fracture.

Brainstorming: What Are the Treatment Goals and Options?

The goals of the treatment of this fracture are:

1. Good long-term functional outcome, i.e., quality of life
2. Avoidance of complications
3. Early range of motion of the hindfoot
4. Anatomical reduction of the joint surface, restoration of the shape of the calcaneus, and establishment of normal hindfoot relationships
5. Return to work

Treatment options include:
Non-operative care:

1. Rest, ice, compression, and elevation followed by early range of motion

Operative care:

1. Minimally invasive reduction and fixation
2. Open reduction and internal fixation
3. Primary subtalar fusion

Evaluation of the Literature

A search of PubMed and Medline databases from January 1993 to May 2016 using the MeSH keywords "calcaneus" AND "fracture, bone" with the subheadings "treatment", "therapy", and limited to "humans", "clinical trial", "meta-analysis", "practice guidelines", "randomized control trial", "review", "English", and "all adult: 19+ years" yielded 63 articles for review.

Detailed Review of Pertinent Articles

The following discussion aims to provide evidence-based data pertinent to treatment of the case presentation.

Non-operative Treatment

Non-operative treatment remains a reasonable option for certain displaced intra-articular calcaneus fractures. Although there is no Level I evidence in the literature regarding non-operative treatment, this management of calcaneus fractures should be considered in certain population groups. In a large prospective randomized controlled multicenter trial [5] including 471 displaced intra-articular calcaneus fractures, a comparison of operative versus non-operative management showed that there is a combination of demographic features that favor non-operative treatment. The combination of ice, elevation, early range of motion, and good follow-up can be used in patients who are older than 60, smokers, sedentary workers, or in cases with a simple fracture pattern.

Howard and colleagues demonstrated the importance of gross varus or valgus deformity in patients treated non-operatively [4]. If this is avoided, patients are less likely to have complications. Non-operative treatment includes ice, elevation, compression wrapping, and early range of motion with full weight bearing at 6 weeks in order to prevent stiffness.

There are no Level I studies to support or refute non-operative treatment. The existing RCTs comparing operative versus non-operative treatment [5, 8–10] conclude that certain population subgroups with simple fracture patterns might benefit from non-operative care but there are methodological limitations in these investigations, which limit the ability to draw definitive conclusions. These limitations include few studies, limited numbers of patients, and lack of blinding. However, they find that patients with simple fracture types treated non-operatively will uncommonly have serious foot deformities, malunions, or peroneal impingement in the long term.

Two of the goals of calcaneus fracture care, i.e., early range of motion and avoidance of complications, can be achieved with non-operative care of the patient, but they must have a well-positioned hindfoot.

Surgical Options

Minimally Invasive Reduction and Fixation

Small incision surgery is also an option for the treatment of certain calcaneus fractures. It was initially introduced by Essex-Lopresti and is the oldest technique of reduction and fixation of some calcaneus fractures. In a Level IV study, Rammelt and colleagues [11] reported on 61 patients with simple (Sanders type II) fractures that were treated with percutaneous reduction and screw fixation. They concluded that when anatomical reduction is achieved with the aid of arthroscopy or three-dimensional fluoroscopy, patients demonstrate good functional outcome and avoid complications.

Abdelazeem and colleagues [12], in another Level IV study, used a lateral open approach through the sinus tarsi. They accrued 33 patients and followed them for an average of 29 months. Reduction was maintained, and the clinical outcomes using the AOFAS were good with a 3% wound complication rate.

Basile [13], in 2016 with a Level III study, prospectively compared Sanders II and III patients with closed displaced intra-articular calcaneal fractures. Thirty-eight patients were prospectively enrolled and operated upon with a sinus tarsi approach or the "extended L" approach. There were fewer wound complications, the procedure was faster, and all outcomes using modern techniques show equivalency.

With a paucity of Level I and II studies comparing small incision surgery with reduction and fixation to other treatments, the former should be reserved for older, medically complex patients with simple fracture patterns. Consequently, minimally invasive reduction and small incision fixation is not supported by the best evidence in this case.

Open Reduction and Internal Fixation

Open reduction and internal fixation of calcaneal fractures is a topic in orthopedic fracture care that has been heavily debated over the last decades. Despite this, there are no Level I studies showing the efficacy of open reduction and internal fixation. An older meta-analysis [14] looked at all randomized and quasi-randomized control trials that were published in peer-reviewed journals. It could not demonstrate efficacy of ORIF over non-operative care.

The largest series that has been published [5] includes 424 patients with 471 displaced intra-articular calcaneal fractures. These fractures were randomized to surgical or nonsurgical care, and patients were followed from 2 to 8 years. Statistical analysis of stratified subgroups showed no difference in visual analogue scale score or SF-36 between groups. The authors concluded that operative treatment provides the best results when it is chosen after careful selection of patients, taking into consideration several fracture and patient-related factors such as age, gender, smoking history, insurance claims, and patient workload. The patient who represents the ideal candidate for surgery is a young, male, non-smoking heavy laborer with no workers' compensation claim with a closed, severe (Bohler's angle <0°), unilateral calcaneus fracture. These patients demonstrated better functional outcomes (SF-36 and visual analog scores) with surgery compared to non-operative management and at the same time did not demonstrate perioperative complications such as deep infection (4–10%). Operative treatment also significantly reduced risk for future arthrodesis compared to non-operative treatment (3% compared to 17%).

Ibrahim and colleagues [10], in a 15-year follow-up of a previously published randomized controlled trial comparing operative versus non-operative treatment, demonstrated no difference in clinical and radiological outcome between the two groups. The 15-year follow-up looked at 26 of the initial 56 patients. The operative treatment that was implemented initially (open reduction and k-wire fixation) is considered today of only historical interest. The authors report no differences in outcomes, but they did not consider major complications such as deep infection, and there was no subgroup population analysis. Interestingly, they report no subtalar joint fusion for post-traumatic arthritis, although less than half of the patients of the original study were included in their follow-up.

In 2013, a prospective Level II RCT of displaced intra-articular calcaneal fractures was published by Agren [8] with 82 patients. Independent observers looked at the patients using recent outcome scoring scales in the two treatment arms which were "extended L" operative treatment or non-operative care. Primary and secondary outcomes were not different, but the operative arm had slightly better scores for pain and function.

In 2014, another prospective RCT of displaced intra-articular calcaneal fractures was performed in Britain [9]. It was a pragmatic RCT but established Level I evidence for the question of ORIF or non-operative care with this fracture type. With 151 patients accrued, 2-year follow-up, and 95% return of all patients for follow-up, they showed no difference between outcomes in the 2 groups but a higher infection rate in the operative group. A major concern with this study was the fact that no surgeon contributed many cases to the study and it was spread all across Britain (good generalizability but poor specialty care had been demonstrated).

Despite the fact that all the above studies are of good evidence but have methodological limitations [5, 8–10], it is well accepted that operative care in selected patients renders better results compared to non-operative care, provided that anatomical reconstruction is achieved [5, 8]. If the fracture is not adequately reduced, then operative results are similar to non-operative care [9, 10].

Avoidance of complications is of paramount importance in operative calcaneal fracture care. Complications can occur after operative treatment even when performed by experienced surgeons. The long-term outcome is mainly determined by pain, stiffness, and infection. Deep infection with no healing (1–2% of cases) requires a second operation [2, 3]. A surgical reduction and fixation reduces the risk of subtalar arthritis resulting in fusion (from 17% to 3%) [15]. However, this fact should not be used as an isolated parameter to justify operative care in all patients, since more than 80% of the patients who are treated non-operatively do not require a late subtalar arthrodesis [5], and in general, a late fusion offers good results [16]. If a patient requires a late fusion, whether treated with ORIF or non-operatively, the surgical outcome is comparable to a patient who undergoes early ORIF or who has a good result from non-operative care (visual analogue scores 80/100) [16].

A paper by Herscovici [17] describes successful ORIF surgery with patients over 65 years of age. The importance of this paper is the information that with care and good decision-making, even the highest risk patients, the elderly, can be successfully treated with ORIF with few complications.

Subtalar Fusion

Primary subtalar fusion for Sanders IV fractures was shown to be efficacious versus ORIF alone in a multicenter RCT [16]. Over 30 patients were randomly assigned to ORIF or ORIF and then primary fusion. After 2 years, results using modern techniques of outcome measurement showed equivalency between groups. Late subtalar fusion can be predicted by different parameters of the initial injury. The subgroups of patients that are most likely to require late subtalar fusion include heavy laborers, male patients, those with insurance claims, and those with severe displacement of the fracture at presentation (Bohler's angle <10°) [15]. At the same time, there is strong Level II evidence that patients who were initially treated non-operatively due to concomitant medical problems, and had a late fusion for post-traumatic arthritis, demonstrated similar functional outcomes to patients who underwent primary open reduction and internal fixation (80 points on a 100-point analog scale) [15].

Although this patient suffered an injury that demonstrates some of the characteristics that predict a late fusion, the patient is very young, and we do not think that primary fusion offers the best solution. This operation is technically difficult, there is little evidence to support its use, and if the patient subsequently requires a late fusion in the future, this option is still available.

Recent Review Papers and Literature Inconsistencies [14, 18–21]

The recent review papers listed above all summarize the decision-making algorithm for displaced intra-articular calcaneal fractures. These papers all state that each patient has responsible factors for proceeding for surgery or not. It is the same for the soft tissue factors and the different fractures and their classifications and factors that may determine decision-making. The four standard treatment types are all used commonly, but the new literature seems to be favoring less large incision surgery to eliminate higher chances of soft tissue complications. Small incision surgery is becoming more popular with literature to back it up as long as the reduction is achieved and maintained. Indications for small incision surgery and percutaneous reduction and fixation are not clear. Data regarding its efficacy compared to other treatment options show equivalency in outcome [13]. These questions need to be addressed with well-designed multicenter prospective randomized or cohort trials.

Evidentiary Table and Selection of Treatment Method

Based on currently available evidence, the best treatment option for patient RF is open reduction and internal fixation of this fracture. The best evidence that guides decision-making in displaced intra-articular fractures is summarized in Table 26.1 [5, 8–10, 13, 14, 18, 22].

Definitive Treatment Plan

The goal of surgical operation with open reduction and internal fixation is to provide the patient with the best possible anatomic reduction of the joint surface and to respect soft tissues so that the patient avoids complications, has a good range of motion, and thus a good long-term outcome.

Despite the lack of Level I studies to guide treatment, stratification of data (both in relation to the fracture and the patient) is the best decision-making tool for rationalizing treatment choices. The patient in this case and the fracture presented (after smoking cessation advisement) both represent good examples where open reduction and internal fixation would be justified and beneficial. In operative treatment, one should always bear in mind the goals of calcaneus fracture care: restoration of joint anatomy, early range of motion, avoidance of complications, and good long-term functional outcome. Obtaining and maintaining anatomical reduction of the joint surface is extremely difficult with minimally invasive small incision surgery and percutaneous reduction techniques for this fracture given its comminution and displacement. Primary fusion is also not justified from the current available data in the literature.

Prior to surgery, the patient should be aware that calcaneus fractures are life-changing injuries and that the return to pre-injury functional level is a difficult task. An interview and counseling regarding smoking cessation are recommended as well. One recent study demonstrated great differences between intervention (counseling about benefits of smoking cessation) and nonintervention for smoking cessation at 6 months after the hospital discharge [23].

Surgery is performed when soft tissue swelling has decreased (usually between 7 and 16 days). The criteria for best timing for surgical intervention are clinical criteria. Soft tissue recovery is denoted by the presence of the “wrinkle” sign and the epithelialization of all hemorrhagic and serous blisters. If needed, surgery can be postponed for up to 21 days in order to achieve the best soft tissue environment for surgical intervention.

The patient is placed in the lateral decubitus position on the well-padded operating table, with affected side up. A course of intravenous antibiotics is given prior to the surgical incision, and a tourniquet is applied to the thigh of the affected limb. The leg is then flexed 30–45° at the knee and supported by a leg raft so that AP, lateral, axial (Harris), and Broden fluoroscopic views are possible.

The standard L-shaped lateral approach is utilized. The vertical arm of the incision is placed midway between the fibula and the Achilles

Table 26.1 Evidentiary table: A summary of quality of evidence for open reduction and internal fixation for displaced intra-articular calcaneal fractures

Author (year)	Description	Summary of results	Level of evidence
Buckley et al. (2002) [5]	Prospective randomized controlled trial	427 patients, 471 displaced intra-articular calcaneal fractures. Operative versus non-operative care. 2–8 years follow-up. After stratification of groups and excluding insurance claim patients, significantly better results with operative care. Young, healthy patients with simple fractures did better with ORIF	II
Basile et al. (2016) [13]	Comparative cohort	32 patients, operative treatment lateral versus sinus tarsi approach. 12 months follow-up. Authors recommend that sinus tarsi approach is quicker with fewer complications and equal efficacy	III
Griffin et al. (2014) [9]	Pragmatic prospective randomized trial	151 patients, operative versus non-operative. 24 months follow-up. Superior results (function, ROM) with non-operative treatment compared with operative treatment (higher complication rates – Infection)	I
Ibrahim et al. (2007) [10]	Randomized control trial	26 patients, operative versus non-operative. 15 years follow-up. No difference (function and radiology) between operative and non-operative care	II
Gougoulias et al. (2009) [14]	Meta-analysis of randomized trials in patients with intra-articular calcaneal fractures	Operative versus non-operative (5 studies). Impulse compression versus no impulse compression (1 study). Surgery provides better results on ability to return to work. Insurance claims affect the outcome. It is unclear whether general health outcome measures, injury specific scores, and radiographic parameters improve after operative management and whether the benefits of surgery outweigh the risks	II
Agren et al. (2013) [8]	Prospective randomized trial	82 patients, operative care versus non-operative care with 8 years follow-up. Operative care was better as far as outcomes, but these patients had a higher percentage of complications and radiographic osteoarthritis	II
Veltman et al. (2013) [18]	Systematic review of the literature	2 RCTs, 5 Level II studies, 15 Level III studies; 1730 patients. Nondisplaced fractures treated with non-operative care. ORIF/minimally invasive surgery for simple fracture types. ORIF for complex fractures types in healthy patients. Avoid complications	II

tendon. The horizontal arm is placed in line with the fifth metatarsal. Without undermining the edges, a full thickness soft tissue flap is then carefully developed, starting at the point where the two arms of the incision meet. Meticulous elevation of the flaps along with the sural nerve, peroneal tendons, retinaculum, calcaneofibular, and talocalcaneal ligaments exposes the lateral wall. K-wires are then placed at the inferior fibula, talus, and cuboid to serve as retractors. The lateral wall fragment is then identified and flipped down or removed from the field. Attention is then drawn to the anteromedial fracture fragment, or "constant fragment", which includes the sustentaculum tali as this is the most important osseous landmark in the reconstruction of displaced intra-articular calcaneal fractures. The reduction starts from anteromedial and continues posterolateral. Attention is paid throughout the procedure to axial alignment of the calcaneus in order to avoid any varus deformity. The medial wall is directly or indirectly reduced while avoiding varus position. The tuberosity is reduced to the "constant" or sustentaculum fragment, usually with the aid of Schanz pin and K-wires. This maneuver ensures the correct length and height of the tuberosity. The reduction can be facilitated with the use of manual traction, elevators, K-wires, mini distractors, longitudinal traction, and Schanz pins. We find temporary placement of threaded K-wires extremely useful, either small (1.25/1.6 mm) to hold fracture fragments or larger wires (2.0/2.5 mm) to assist with tuberosity reduction.

The lateral articular surface is then reduced and provisionally fixed to the “constant” piece with smooth or threaded K-wires keeping in mind that these should not obstruct the placement of subchondral lag screws. After correct restoration of the length, height, axial alignment, anterior anatomy, and Gissane’s angle, definitive fixation can then be performed. The first goal is to maintain reduction of the articular surface and support the subchondral bone. This is achieved with the use of subchondral lag screws. The direction of this screw is important since it has to “capture” the sustentaculum piece while avoiding the structures of the neurovascular bundle (tibial artery and nerve) that are in close proximity with the tip of the screw. Next, the surgeon must decide whether or not to use bone substitutes to fill the void that has been created after elevation of the articular surface. The answer remains unclear. Some surgeons use conventional plates or locking plates, and some use bone graft, while others never use bone graft. What is not debated is the use of low-profile plates and peripheral fixation in order to avoid placing hardware under the apex of the surgical incision. Closure is then performed in two layers over a drain if needed. Foot elevation, non-weight bearing, and early range of motion are the cornerstones of postoperative management. Non-weight bearing for up to 10 weeks is favored.

Predicting Long-Term Outcomes

Regarding long-term outcomes, it has been suggested that the primary prognostic determinant for a calcaneal fracture is the amount of initial injury involved [20]. A carefully planned and executed open reduction and internal fixation and avoidance of complications are the two factors in a given clinical scenario that determine the outcome. Wound infection rates for lifetime are about 2%, while subtalar arthrosis rates are near 100% with virtually all patients having at least mild late subtalar pain [20]. One study [24] showed equivalency in a biomechanical comparison of locking and nonlocking plates for calcaneal fixation. On another topic, the risk of ST fusion is about 3% [15]. Most patients will return to work, but all patients will need to decrease workload on the foot if they do a labor job [25]. Long-term outcome of displaced intra-articular calcaneal fractures of 10–20 years is now in the literature [26]. One paper [27] shows that if an institutional fracture load (operatively treated calcaneal fractures) is not greater than one per month, then the rate of infection and osteoarthritis increases.

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Talus Fractures

27

Hassan R. Mir and Roy Sanders

EQ: 42-Year-Old Female with Ankle Pain

Case Presentation

EQ is a 42-year-old female who presents to the emergency department with a chief complaint of right ankle pain after being involved in a high-speed motorcycle accident. She denies any other injuries or pain and is unable to bear any weight on her right lower extremity.

On primary survey she demonstrates a GCS of 15 and a patent airway and is hemodynamically stable. On secondary survey, no gross deformity is noted to her right lower extremity.

Her past medical history is negative, and she takes no medications and has no allergies.

Physical examination demonstrates a healthy appearing female in no acute distress. Examination of her right ankle demonstrates no gross deformity to the right ankle, but moderate effusion is noted. The patient is unable to range her ankle secondary to pain. There are no open wounds present. The dorsalis pedis and posterior tibialis pulses are palpable and equal. Sensation to light touch is intact in all dermatomal distributions. Calf and foot compartments are soft and compressible. Ecchymosis is noted. The patient is able to flex and extend all of her toes. No pain or deformity is noted in the knee or proximal leg.

Radiographs and CT scan images of the right foot are demonstrated in Figs. 27.1a–c and 27.2a–c.

Interpretation of Clinical Presentation

The patient's history, exam, and radiographic findings are consistent with a fracture of the right talar neck with dislocation of the subtalar joint. Injuries to the talus usually result from hyperdorsiflexion of the ankle, with fractures and fracture dislocations of the talar neck accounting for 50% of all major injuries to the talus [1, 2]. Talar neck fractures are significant because of the frequency and severity of the complications and long-term disability. The patient sustained this injury from a high-energy mechanism; therefore, consideration should be given to clearance of the head, chest, and abdomen by the emergency department or trauma service to assure that no subtle or occult injuries are present. Many patients with talar neck fractures are polytrauma victims, and associated injuries to the musculoskeletal system are common and were present in 64% of Hawkins' patients.

H. R. Mir (✉) · R. Sanders
Florida Orthopedic Institute, University of South Florida, Tampa, FL, USA
e-mail: hmir@floridaortho.com

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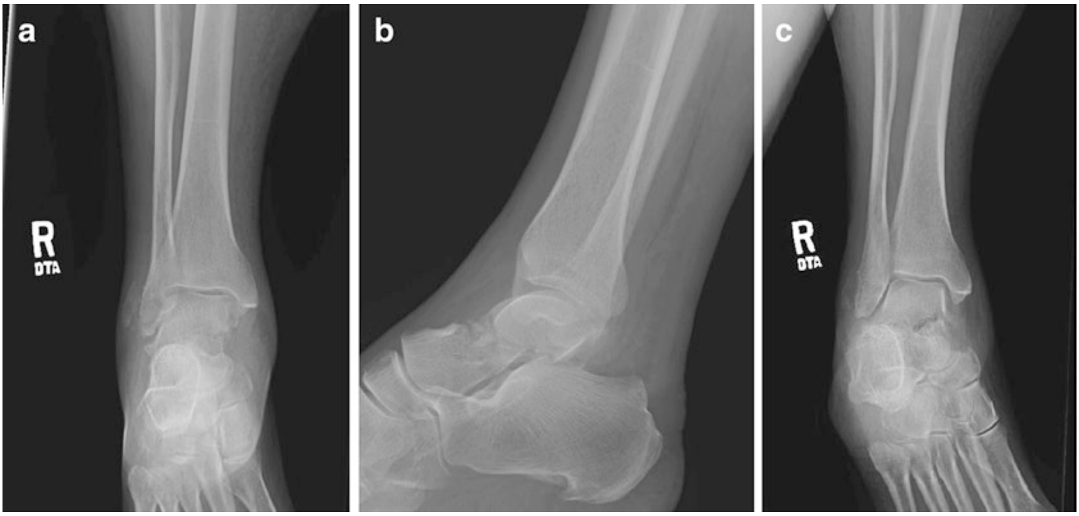

Fig. 27.1 (**a**) AP radiograph ankle (**b**) Lateral radiograph ankle (**c**) Mortise radiograph ankle

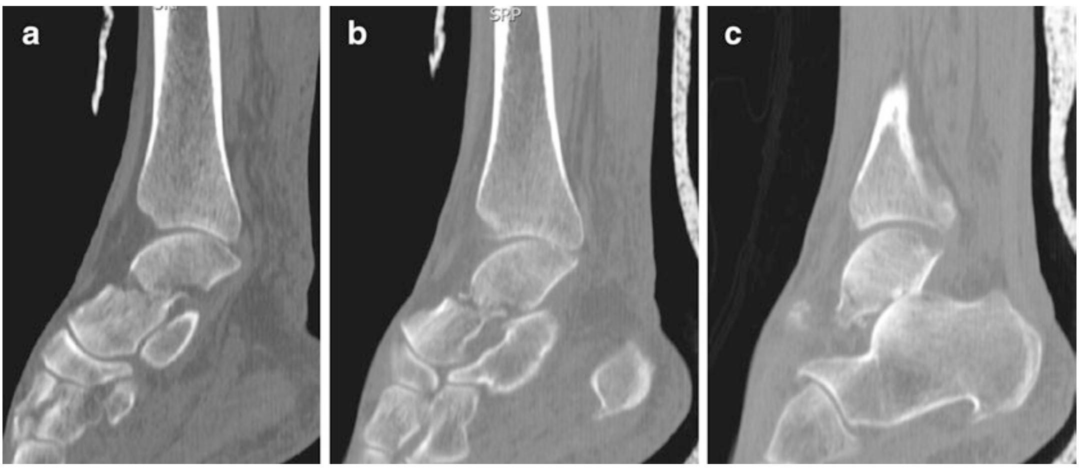

Fig. 27.2 (**a**–**c**) Sagittal CT ankle

The radiographs that are obtained should include an anteroposterior (AP), a lateral, and an ankle mortise view; a modified AP view of the foot may be required [3]. The Canale view is obtained by pronating the foot 15° while the X-ray beam is directed 75° from the horizontal plane, which allows for a profile view of the talar neck unimpeded by the calcaneus. The degrees of fracture comminution, neck alignment, and articular congruity of talar fractures are important determinants of outcome, but they often cannot be assessed by plain radiography alone. Multiplanar computed tomography (CT) using 1-mm acquisitions allows optimal evaluation, detects fractures initially missed on radiographs, and determines further extent of fractures [4]. A review of patient EQ's plain radiographs and CT scan images shows a displaced, comminuted fracture of the talar neck with dislocation of the subtalar joint but with congruity of the tibiotalar joint.

The most commonly used classification of talar neck fractures was described by Hawkins in his report on 57 talus fractures published in 1970 [1]. This classification was based on the radiographic appearance of the talus at the time of injury and divided these talar neck fractures into three groups. In group I injuries, the vertical fracture in the talar neck is non-displaced, with the talar body maintaining its normal relationship with both the ankle and subtalar joints. In group I injuries, only one of the three main sources of blood supply to the talus is interrupted: the vessels that enter the foramina on the dorsolateral aspect of the talar neck and progress proximally into the body. In group II injuries, the vertical fracture of the talar neck is displaced, and the subtalar joint is either subluxated or dislocated. Medial dislocations are more common, and if the subtalar dislocation is complete, the injuries can be open because of the thin subcutaneous layer of tissue at the level of the ankle joint. In group II injuries, at least two of the three sources of blood supply to the talus are interrupted: (1) the blood supply proceeding proximally from the talar neck (as in group I) and (2) the blood supply entering vascular foramina located inferiorly in the roof of the sinus tarsi and tarsal canal. The third main source of blood supply, the entering vascular foramina on the medial surface of the talar body, may also be injured. In group III injuries, the vertical fracture of the talar neck is displaced, and the talar body is dislocated from both the ankle and the subtalar joints, often posteromedially between the posterior surface of the tibia and the Achilles tendon. The talar head maintains its normal relationship with the navicular. All three of the main sources of blood supply to the talar body are damaged in group III injuries. More than 50% of group III fracture dislocations are open injuries, and in closed injuries the overlying skin and occasionally the neurovascular bundle are in jeopardy. Canale and Kelly added a fourth type of dislocation in their report on a series of 71 talus fractures published in 1978: group IV, in which a fracture of the talar neck is associated with a dislocation of the body from the ankle or subtalar joint and a dislocation or subluxation of the talar head from the talonavicular joint [3]. In this injury, damage to the vascularity of both the body (as in group III injuries) and the head and neck fragments is possible. Vallier and associates further subclassified group II injuries in 2014 into those with a subtalar joint subluxation and less likely vascular disruption (group IIA) and those with a subtalar joint dislocation and more likely vascular disruption (group IIB) [5]. EQ's injury would be classified as a group IIB fracture of the talar neck with an associated subtalar dislocation.

The blood supply to the talus has been studied in great detail because of the incidence of complications after fractures and dislocations [6–8]. Although early reports indicated poor vascular flow, more recent investigators note the presence of a rather extensive extraosseous and intraosseous blood supply to the talus. However, since most of the talar surface is covered with articular cartilage (60%) and no muscles originate or insert into this bone, the areas available for vessels to enter are few. The majority of the surface of the talar neck, the medial surface of the body below the medial malleolus, the sinus tarsi, and the posterior tubercle are devoid of cartilage, and these areas therefore receive the blood supply to the talus. The extraosseous arteries to the talus include multiple branches from the anterior tibial, peroneal, and posterior tibial arteries. The anterior tibial artery gives rise to the anterolateral malleolar artery, which may anastomose with the perforating peroneal artery to form the artery of the tarsal sinus. The posterior tibial artery supplies the talus through multiple branches, the major one being the artery of the tarsal canal that gives off the deltoid branch, which passes between portions of the deltoid ligament and supplies the medial periosteal surface of the talar body. The current consensus in the literature is that the artery of the tarsal canal with its anastomotic network to the sinus tarsi artery provides the major blood supply to the talus. Anastomoses between the various intraosseous arteries are responsible for the survival of the talus in severe injuries [7, 9]. The lack of these connections in certain areas of the talus may also explain why avascular necrosis (AVN) can affect portions of the talar body differentially [10]. An attempt at closed reduction of EQ's injury in the emergency department would be warranted to try and minimize soft tissue and vascular insult.

Declaration of Specific Diagnosis

EQ is a 42-year-old female who presents with a Hawkins group IIB talar neck fracture with dislocation of the subtalar joint.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Reduction of the subtalar dislocation
2. Rigid stabilization of the talar neck fracture to allow range of motion
3. Fracture union in anatomic alignment
4. Avoidance of long-term complications

Treatment options include:
Conservative:

1. Closed reduction and casting

Surgical:

1. External fixation
2. Open reduction with internal fixation (ORIF):
   (a) Timing of surgery
   (b) Approach
   (c) Fixation:
      - Screws
      - Plates and screws

Evaluation of the Literature

In order to identify relevant publications on talar neck fractures, a PubMed search was performed. Keywords included "talus fracture" and "neck." The search was limited to human clinical trials and meta-analyses in the English literature from 1946 to 2017. This search identified 258 abstracts that were reviewed. From this search, 48 articles were read, and reference lists were reviewed, and 37 publications were selected for citation in accordance with the guidelines for this textbook, with all references from 1975 to the present. One additional citation was included, which was Hawkins' classic article on talar neck fractures from 1970.

Detailed Review of Pertinent Articles

The following discussion explores the relevant literature in order to determine the most optimal treatment for EQ.

Conservative/Nonoperative Treatment

In retrospective series from the 1970s, many talar neck fractures were treated with closed reduction and cast immobilization for a minimum of 6 weeks, followed by a non-weight-bearing brace for a minimum of 12 weeks or until there was radiographic evidence of fracture union [1–3, 11, 12]. Open reduction was reserved for cases in which satisfactory alignment could not be obtained by closed methods. There was limited use of internal fixation in cases of open reduction, mainly consisting of Kirschner wires. In Hawkins' series of 57 talus fractures published in 1970, 60% (14/24) of group II fractures required an open reduction to obtain satisfactory alignment, with fair/poor results in 33% and AVN in 42%. In the series of 40 talus fractures reported by Penny and colleagues in 1980, 64% (7/11) of group II fractures had unsatisfactory results. The authors did not report the number of open reductions but did conclude that accurate reduction and rigid fixation to allow early motion could be beneficial. Of the 30 group II fractures in Canale's series of 71 talus fractures published in 1978, 43% (13/30) had fair/poor results, and 50% (15/30) developed AVN, but only 33% (10/30) were treated with an open reduction. In 1977, Lorentzen and colleagues reported on a large series of 123 talus fractures, 53 of which were group II fractures. Only 4/53 were treated with open reduction, with 24% developing AVN and

42% having severe subjective complaints of pain and impaired walking ability.

Because of the difficulties in obtaining an acceptable closed reduction, and due to poor clinical results with this treatment protocol for displaced fractures, many authors in the 1980s advocated for ORIF of all Hawkins groups II–IV fractures [13–15]. The advantages of ORIF include anatomic restoration of the neck, congruity of the subtalar joint, and stability of the fracture to allow early motion of the ankle and subtalar joints with maintenance of reduction until bony union. In 1985, Szyszkowitz and colleagues published their results of 85 talus fractures treated with emergent ORIF, with poor results in just 1 of 12 group II fractures. Comfort and colleagues published a series of 36 talus fractures in 1985, 28 of which were displaced and underwent early ORIF, with all but 2 of their patients able to return to work. Grob and colleagues reported in 1985 on a series of 41 talus fractures treated with emergent ORIF, with all cases of AVN (16%) occurring in type III and IV fractures. More recent series also advocate for ORIF of displaced group II–IV injuries, with 6 weeks of cast immobilization and 12 weeks of non-weight bearing reserved for non-displaced group I fractures [16–22].

Temporizing Treatment

External fixation or splinting can be used for temporization in situations when definitive ORIF must be delayed. Clinical situations that may present this challenge include maintenance of joint reduction in polytrauma patients who are not medically stable for immediate ORIF during the initial trip to the operating room and patients whose soft tissues are not suitable for ORIF due to severe edema or open-wound contamination. The use of an external fixator or universal distractor may also be a valuable aid in obtaining reduction of the talar body in group III and IV injuries. Also, those patients with persistent ankle or subtalar instability from concomitant fractures or ligamentous injuries after ORIF of the talus may be candidates for external fixation for joint stability. In the series of 50 talus fractures reported by Pajenda and colleagues in 2000, external fixation was applied in seven cases for associated unstable comminuted fractures of the calcaneus or ankle joint and in cases of dislocated open fractures with residual instability after ORIF [20]. Their series included 14 group II fractures, of which 85% (12/14) had an excellent result. There were no reports in the available literature on the use of external fixation alone as definitive fixation for the treatment of talar neck fractures.

Operative Approaches

Timing of Surgery

Dislocation of the subtalar and/or ankle joint in association with talar neck fractures should be reduced emergently to prevent soft tissue compromise [22]. If the reduction cannot be accomplished with closed methods under sedation, and there is either skin compromise in groups II–IV injuries, a neurovascular deficit in the case of group III or IV injuries with the talar body resting on the posteromedial structures, or open wounds, then the patient should be taken emergently to the operating room for debridement and reduction of the fracture.

The timing of definitive ORIF for displaced fractures of the talar neck remains controversial. There was a shift in management protocols toward emergent ORIF of talar neck fractures after the publication of three independent papers in 1985 that were previously described [13–15]. The emergent treatment of these injuries was also advocated by subsequent reports that claimed a lower incidence of AVN than historical series, due to their early treatment protocols [16, 18]. Elgafy and colleagues reported in 2000 that in their series of 60 talus fractures, which included 27 talar neck fractures treated by early ORIF, only 16% developed AVN. In 1995, Frawley and colleagues published their series of 26 talar neck fractures in which only 15% (4/26) went on to develop AVN. They attributed their low incidence of AVN to early anatomical stabilization of the fracture and advocated for expedient diagnosis and treatment.

However, there have been recent studies that contradicted the results of the previous authors.

In 2004, Lindvall and colleagues reported that in their series of 26 displaced talus fractures, an average delay of 3.5 days to surgical fixation did not appear to affect the outcome, union, or prevalence of osteonecrosis [19]. Similar findings were reported by Vallier and colleagues in their series of 39 talus fractures published that same year, with an average delay of 3.4 days for patients who had development of osteonecrosis, compared with 5.0 days for patients who did not have development of osteonecrosis [22]. In a military report in 2011, Bellamy and colleagues found no correlation between an average surgical delay of 12.9 days and the development of osteonecrosis [23]. A survey of orthopedic trauma surgeons who manage talus fractures in 2005 indicated that 60% of respondents felt that treatment after 8 h was acceptable, and 46% of respondents felt that treatment at or after 24 h was acceptable [24]. In Vallier and associates' more recent series from 2014, 35 of their 80 patients had delayed ORIF (mean, 10.6 days), including 10 with Hawkins group IIB and 10 with Hawkins group III fractures initially reduced by closed methods, and 1 one (5%) of the 20 developed osteonecrosis [5].

Surgical Approach

Most series of ORIF of talar neck fractures report the use of either an anteromedial approach, an anterolateral approach, or dual approaches in order to attain the goal of an anatomic reduction, with many of the authors favoring dual approaches to achieve this goal. The effects of dual surgical approaches to the blood supply of the talus were examined by Prasarn and associates, who defined the boundaries of such dissections and also demonstrated a newly described medial talar neck branch that was inevitably sacrificed secondary to an anteromedial approach [8]. In addition, they found that the anastomotic connection over the superomedial surface of the talus could be disrupted if aggressive dissection was carried out dorsally over the neck. Even so, they acknowledged that a medial approach is almost always mandatory to obtain an anatomic reduction and rigid internal fixation when treating displaced fractures of the talar neck but recommended using extreme caution during surgical dissection to prevent unnecessary additional injury to the vasculature. Specifically, great care should be taken to avoid dissection dorsally and plantarly during both approaches to avoid injury to branches from the dorsalis pedis artery and the anastomotic network in the tarsal canal, respectively.

Fixation

Open reduction with internal fixation of talar neck fractures is commonly performed with the use of small fragment lag screws and positional screws. Positional (non-lag) screws are used in cases with comminution in order to avoid shortening. Although used in many earlier studies, Kirschner wires alone should not be used for fixation because they do not provide sufficient stability [25]. A biomechanical study by Swanson and associates in 1992 showed that in constructs fixed with small fragment screws alone, using a trajectory from posterior to anterior provided the most strength [25]. Anatomic studies show that screws can be placed safely with a posterolateral starting point, and clinical series with percutaneously placed posterior to anterior directed small fragment screws have shown good union rates but have not been without the complications of posttraumatic arthritis, AVN, and sural nerve complications [26–29]. Anteriorly placed screws can be inserted either percutaneously or through open anteromedial and anterolateral approaches utilized by most surgeons to obtain an anatomic reduction of the talar neck. Anterior to posterior directed small fragment screws have been used in several series with excellent union rates achieved and with similar rates of posttraumatic arthritis and AVN [13–16, 18–21, 28, 30].

Mini-fragment plates and screws have been compared to posterior small fragment screws in cadaveric models with significant comminution [31, 32]. In a cadaveric biomechanical study published in 2006, Charlson and associates reported that plate fixation may offer substantial advantages in the ability to control the anatomic alignment of comminuted talar neck fractures, but it did not provide any biomechanical advantage compared with axial screw fixation. In another cadaveric biomechanical study from 2007, Attiah and associates found that anterior plate fixation provided equivalent stability to posterior screw fixation. Clinical series have shown that the use of lateral mini-fragment plates and screws with medial small fragment screws or mini-fragment plates and screws shows similar union rates and complication rates to screw-alone techniques [17, 22, 33]. The use of titanium implants may be considered to allow for future magnetic resonance imaging (MRI) examinations to assess for the development of AVN [34].

Literature Inconsistencies

As can be seen from the preceding sections, areas of controversy exist in the literature with regard to surgical timing, surgical approach, and method of fixation for talar neck fractures.

The majority of the evidence is driven by retrospective case series and cadaver studies. However, with rare injuries, it is difficult to perform prospective randomized trials to obtain level 1 evidence to guide treatment.

Evidentiary Table and Selection of Treatment Method

The clinical studies that influence the treatment of EQ are noted in Table 27.1 [5, 16, 19, 21, 22, 28]. Based on the literature, the best treatment in this case of a Hawkins group IIB talar neck fracture with a subtalar dislocation would be ORIF.

Definitive Treatment Plan

The operative goal in treatment of talar neck fractures is to obtain and maintain anatomic alignment with stable fixation to allow early motion

Table 27.1 Evidentiary table: A summary of the level of evidence for open reduction with internal fixation (ORIF) of talus fractures

Author (year)	Description	Summary	Level of evidence
Lindval et al. (2004) [19]	Retrospective cohort study	Twenty-six talus fractures were followed for 48 months. All closed fractures united. Delay in surgical fixation did not affect outcome or complications. Posttraumatic arthritis was more common than AVN	III
Vallier et al. (2004) [22]	Retrospective cohort study	Thirty-nine talus fractures were followed for 36 months. No correlation was found between surgical delay and AVN. Complications were associated with neck comminution and open fractures	III
Sanders et al. (2004) [28]	Retrospective cohort study	Seventy operatively treated talus fractures were followed for 5.2 years. Functional outcomes varied, mostly dependent on the development of complications. The incidence of reconstructive surgery increased over time, most commonly for subtalar arthritis	III
Schulze et al. (2002) [21]	Retrospective cohort study	Eighty talus fractures were followed for 6 years after fixation. Ankle or subtalar arthrosis occurred in two thirds of the patients. AVN occurred in 9/80 fractures	III
Elgafy et al. (2000) [16]	Retrospective cohort study	Sixty talus fractures were followed for 30 months postoperatively. 53% had subtalar arthritis, 25% had ankle arthritis, and 16% had AVN	III
Vallier et al. (2014) [5]	Retrospective cohort study	Eighty-one talus fractures were followed for 30 months. Separating Hawkins type II fractures into those without (type IIA) and those with (type IIB) subtalar dislocation predicts the development of AVN. Delaying reduction and definitive internal fixation does not increase the risk of developing osteonecrosis	III

after soft tissue healing occurs until bony union. Group IIB talar neck fractures are reduced urgently but then typically operated on as soon as the patient's medical condition and soft tissues allow. Dual approaches are usually necessary to ensure anatomic reduction. Simple fracture patterns are fairly amenable to fixation with small fragment screws alone, while severely comminuted fractures are much more challenging to align and stabilize and may require the use of mini-fragment plates and screws or positional screws with corticocancellous bone graft from the distal tibia or iliac crest.

The patient is placed supine on a radiolucent table with a bump under the ipsilateral buttock to allow ease of access to the lateral side of the foot and external rotation of the hip intraoperatively to allow access to the medial side of the foot. After the patient is prepped and draped in a normal sterile fashion, anteromedial and anterolateral approaches are made as necessary to allow visualization of the talar neck to ensure anatomic alignment and rotation of the neck, as well as anatomic reduction of the subtalar joint. The anteromedial approach is made starting at the navicular tuberosity and continued proximally between the tibialis anterior and tibialis posterior tendons, with care to avoid damage to the saphenous vein. The incision should allow for the possibility of extension to a medial malleolar osteotomy in select cases that require more proximal visualization of the talar body. Care is taken to avoid excessive soft tissue stripping dorsally along the talar neck and plantarly near the body to prevent iatrogenic devascularization. The talonavicular joint capsule is incised to allow joint subluxation for visualization of the talar head for medial countersunk lag screw or positional screw placement in cases where the talar head cartilage must be violated for screw containment. The anterolateral incision is made in line with the fourth ray. Care should be taken to avoid injury to branches of the superficial peroneal nerve. The inferior extensor retinaculum is incised, followed by dissection of the extensor digitorum brevis distally and laterally in a continuous sleeve to allow visualization of the sinus tarsi contents. This approach provides excellent exposure of the lateral aspect of the talar neck and body, and careful plantar dissection permits visualization of the subtalar joint. Reduction and provisional fixation can be obtained by working through both the anteromedial and anterolateral approaches. Definitive fixation is performed medially and laterally in accordance with the fracture characteristics, with small fragment lag screws or positional screws, or with mini-fragment plates and screws. Titanium implants and bioabsorbable pins may be useful to consider. Intraoperative fluoroscopy is used to ensure anatomic alignment of the talar neck and subtalar joint, with AP, lateral, mortise, and Canale views. The wounds are closed in a standard-layered fashion. Modified Allgower-Donati sutures may be used in the skin to maximize cutaneous blood flow. The patient is placed into a well-padded short leg posterior splint with medial and lateral plaster stirrup support. Ankle range of motion is permitted after suture removal in 2–3 weeks with a removable brace, and weight bearing is protected for 10–12 weeks until fracture union is evident clinically and radiographically with bridging trabeculae. Weight bearing is then progressed in a protective boot.

Predicting Long-Term Outcomes

Functional outcomes vary and are frequently determined by the complications of arthritis and AVN that occur after treatment of talar neck fractures [28]. In a series of 70 operatively treated talus fractures followed for 5.2 years published in 2004, Sanders and associates noted that the incidence of secondary reconstructive surgery following talar neck fractures increases over time and is most commonly performed to treat subtalar arthritis or misalignment [28]. Open fractures and fractures with comminution have been shown to be associated with an increased rate of complications, particularly avascular necrosis and posttraumatic arthritis [19, 22, 28]. Overall, subtalar arthrosis is more common than AVN after displaced talar neck fractures [1–3, 5, 7, 9–17, 19–22, 24, 25, 27, 28]. The results of group II talar neck fractures are somewhat difficult to extract from the literature as the numbers are small, and the complication rates in many of the available series are not separated by injury type. No series had significant rates of nonunion reported for group II fractures. Most series had arthrosis of the subtalar joint regardless of open or closed treatment in a large percentage of talar injuries, with varying rates reported for group II injuries: Canale and Kelly, 20% (6 in 30); Penny and Davis, 29% (4 in 14); Vallier and associates, 26% end stage (6 in 23); and Lindvall and associates, 100% (10 in 10). In Vallier and associates' series from 2014, 21% of group IIA fractures had subtalar arthritis (4 of 19), while 25% of group IIB fractures had subtalar arthritis (4 of 16). A cadaver study by Chan and associates showed the difficulty in assessing talar neck alignment using plain radiography as is done clinically in the operating room by most surgeons [35]. Varus alignment of the talus can lead to significant hindfoot internal rotation and forefoot adduction, and malreduction of 2 mm has been demonstrated to significantly alter the contact characteristics of the subtalar joint, possibly leading to short-term pain and long-term degenerative arthrosis [36, 37].

AVN in the talus is usually recognized on plain radiographs within 6–8 months from the time of injury or earlier on MRI [1, 34]. The Hawkins sign is a subchondral radiolucent band seen at 6–8 weeks, indicating that osteonecrosis is unlikely [1]. In the series reported by Lindvall and associates, an analysis of the accuracy of the Hawkins sign for predicting the development of AVN showed that the sensitivity was 67% (6 of 9), the specificity was 86% (6 of 7), and the accuracy was 75% (12 of 16). Thus, the sign was a good predictor of the development of osteonecrosis ($p = 0.06$). The AVN rates in the literature reported for group II fractures vary considerably: Penny and Davis, 20% (2 in 11); Hawkins, 42% (10 in 24); Canale and Kelly, 50% (15 in 30); Grob and associates, 17% (1 in 6); Comfort and associates, 57% (8 in 14); Pajenda and coworkers, 7% (1 in 14); Lindvall and coworkers, 40% (4 in 10); and Vallier and coworkers (2004 series), 39% (9 in 23). In the 2004 series reported by Vallier and coworkers, an overall 37% of patients with AVN (7 of 19) demonstrated revascularization of the talar dome without collapse. In Vallier and coworkers' series from 2014, 0% of group IIA fractures had AVN (0 of 19), while 25% of group IIB fractures had AVN (4 of 16).

Subtalar arthritis and AVN that fail conservative treatment modalities including bracing may require salvage procedures such as arthrodesis, which are beyond the scope of this chapter on acute fracture management.

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Lisfranc Injuries

28

Basem Attum, Moses Adebayo, and A. Alex Jahangir

ST: 28-Year-Old Male with Foot Pain

Case Presentation

ST is a 28-year-old male who presents to the ER with a chief complaint of right foot pain after a high-speed MVA. He denies any loss of consciousness. On primary survey, he has a GCS score of 15 and patent airway and is hemodynamically stable. On secondary survey, ecchymosis is present on the plantar aspect of the right midfoot. His past medical history is unremarkable, and he takes no medications and has no allergies.

On physical exam of the foot, all distal pulses of the lower extremity are present, and he is neurologically intact. He is tender to palpation over his midfoot.

Radiographs and CT scans are below (Figs. 28.1, 28.2, 28.3,28.4, 28.5, and 28.6).

B. Attum · A. A. Jahangir (✉)
Department of Orthopedic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA
e-mail: alex.jahangir@vanderbilt.edu

M. Adebayo
Department of Orthopedic Surgery, Howard University, Washington, DC, USA
e-mail: moadebayo@huhosp.org

Interpretation of Clinical Presentation

The goal of treatment is to obtain a minimally painful functional foot [1].The clinical presentation is consistent with a dorsally displaced Lisfranc fracture from high-energy trauma. A thorough history should include details of when and how the injury occurred along with a complete physical exam evaluating for additional injuries. Determining the direction of forces applied to the foot during trauma may assist in identifying the structures involved. For example, inversion forces lead to disruption of the dorsal and interosseous ligaments, while eversion forces involve disruption of the plantar and interosseous ligaments [2].

The chief complaint is often pain with weight bearing [3]. Neurovascular status should be evaluated, and identifying the condition of the soft tissue is of utmost importance. Examination of the skin to identify swelling, blisters, wounds, and ecchymosis is necessary to establish the integrity of the skin and soft tissues. Although not pathognomonic, plantar ecchymosis is highly suggestive of a Lisfranc injury [4]. Other findings include pain with palpation directly over the dorsal aspect of the involved TMT joint. This is called the "piano key test", which is performed by grasping the metatarsal of the involved joint, then plantar flexing and dorsiflexing the joint. The most specific test is a positive compression test which is considered positive when compression

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Fig. 28.1 Lateral view of the foot

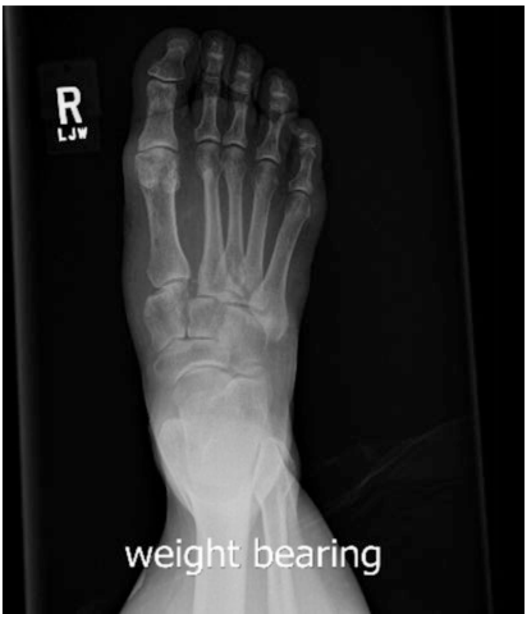

Fig. 28.2 AP view of the foot

Fig. 28.3 Oblique view of the foot

between the first and second metatarsal elicits pain. In some instances, this injury can be mistaken for an ankle injury. The ankle is usually stable and pain-free, and there is no presence of swelling or ecchymosis in Lisfranc injuries [5].

The standard radiographs obtained are AP, lateral, and oblique views. On the AP view, alignment of the medial border of the second metatarsal and medial cuneiform and alignment of the medial border of the first metatarsal and medial cuneiform should be evaluated. On the lateral view, the superior border of the metatarsal base should align with the superior border of the medial cuneiform. On the oblique view, alignment of the medial border of the fourth metatarsal and the cuboid can be viewed [6]. Indications of instability include greater than 2 mm of metatarsal subluxation relative to the corresponding cuneiform, medial cuboid and a medial cuneiform second metatarsal distance of greater than

Fig. 28.4 Axial CT foot

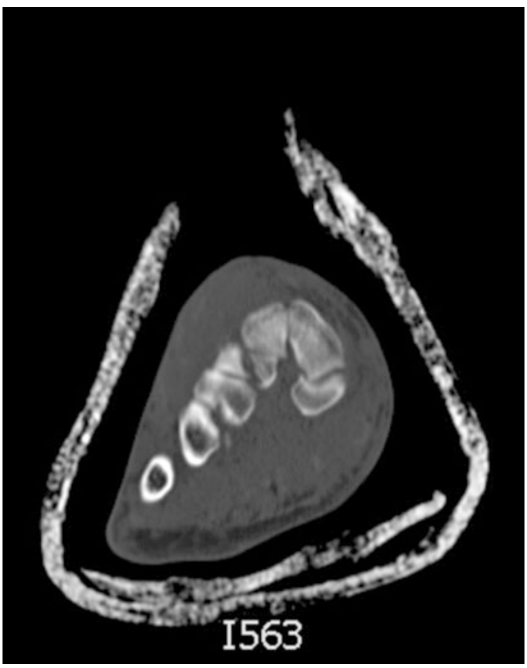

Fig. 28.5 Coronal CT foot

5 mm, or a greater than 2 mm difference compared to the normal contralateral side. The "candle flame sign" is a diastasis greater than 5 mm between the medial and intermediate cuneiforms, between the medial cuneiform and the second

Fig. 28.6 Sagittal CT foot

metatarsal base, or between the bases of the first and second metatarsals signifying a ligamentous lesion [7]. A common radiographic sign of instability is the "fleck sign" seen on AP and oblique radiographs representing an avulsion fracture of the Lisfranc ligament between the first and second metatarsal bases that is seen in 90% of cases [8, 9]. If there is any question if an injury is present, weight-bearing views and/or abduction stress views should be taken. In ST's case, weight-bearing images and CT scan were performed.

Thorough investigation is needed for any suspected Lisfranc injury. Subtle Lisfranc injuries are overlooked in up to 20% of cases as these subtle sprains have a weight-bearing diastasis of less than 2 mm compared with the opposite side and tenderness along the medial midfoot as the only clinical feature. In regard to stress testing, the passive pronation abduction test is performed by eliciting pain on abduction and pronation of the forefoot while the hindfoot is fixed [9–11]. If an MRI is ordered, positive findings are edema at the tarsometatarsal joint, bone bruise, subluxation, or ligament tear. Positive findings on CT scan are 1 mm of subluxation [5].

Declaration of Specific Diagnosis

ST is a 28-year-old male who presents with a closed dorsally displaced Lisfranc fracture.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Anatomic reduction of the TMT joint
2. Rigid internal fixation
3. Minimizing risk of post-traumatic degenerative arthritis
4. Early functional rehabilitation to include ROM of the foot and ankle

Treatment options include the following:
Conservative/non-operative management:

1. Casting

Surgical:

1. External fixation
2. Immediate open reduction and internal fixation:
   (a) Screws
   (b) Articular spanning dorsal plating
3. Closed reduction and percutaneous pinning
4. Staged ORIF
5. Primary arthrodesis

Evaluation of the Literature

In order to identify relevant literature on Lisfranc injuries, a PubMed search was performed. Keywords in the search included "tarsometatarsal injury", "operative treatment for lisfranc injuries", "Percutaneous Fixation of lisfranc injuries", "Open reduction and internal fixation", and "Non-operative management". The search was limited to clinical trials, meta-analysis, randomized control trials, review articles, and journal articles in English involving human subjects. Three hundred seventy-six abstracts were identified. Of these, 100 articles were read along with references being reviewed. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

Multiple treatment options are available for this patient with a Lisfranc fracture. The following discussion identifies the current and relevant literature to determine optimal treatment.

Epidemiology, Anatomy, and Classification

Tarsometatarsal injury (TMT), also known as Lisfranc injury, is a rare injury accounting for 0.2% of all fractures [12, 13]. Dorsal displacement is often present in Lisfranc injury as the dorsal ligament in the TMT articulation is weaker than the plantar ligament [12]. Compartment syndrome and neurovascular injuries have been reported following Lisfranc fracture and require immediate attention [13, 14]. These injuries can be associated with ligament disruptions and tarsal/metatarsal fractures [12, 14].

Anatomy

The TMT joint is formed by the five metatarsals that contribute to the plantar arch distally and the three cuneiforms and cuboid proximally [13, 15]. All articulations of the joint are crossed by plantar and dorsal TMT ligaments [14]. The second to fifth metatarsal base are linked by intermetatarsal ligaments [14]. The Lisfranc ligament is a plantar interosseous ligament from the lateral side of the medial cuneiform to the medial side of the base of the second metatarsal [13, 16]. The midfoot is divided into the lateral, middle, and medial column by three separate synovial articulations. The lateral column consists of the articulations of the fourth and fifth metatarsal with the cuboid and is the most mobile. The middle column consists of the middle and lateral cuneiform and the second and third metatarsal and is the most rigid [15, 16]. The medial column is made up of the medial cuneiform and base of the first metatarsal and is also a rigid structure [15, 16]. These medial and middle columns allow the foot to function as a lever during normal gait [15].

Several attempts have been made to classify Lisfranc injury from the Quenu and Kuss classification in 1901 [17] to the Hardcastle classification in 1982 [18] and the Myer classification in

1986 [19]. Despite numerous classification schemes, none have been able to reliably correlate with treatment and outcomes [6].

Conservative Management

Non-operative treatment is only recommended for ligament sprains or partial tears where there is no static or dynamic instability [1]. Treatment with immobilization has generally resulted in poor results such as extended immobilization, loss of reduction, and need for arthrodesis [9]. In unstable injuries, closed reduction followed by casting is associated with poor immobilization due to further displacement of the disrupted capsular structures and ligaments along with the diminished swelling of the soft tissues [20]. Treatment usually consists of a short walker boot with protected weight bearing for 2 weeks. Clinical exam is then performed, and if there is no tenderness with weight bearing or diastasis on radiographs, the patient can progress to weight bearing in the boot. Weight bearing out of the boot is allowed when patients are pain-free with the abduction stress test, which usually occurs 6–8 weeks after injury. Rigid orthotic support is then used for a period of 6 months. No running on uneven surfaces is recommended for 3–4 months and only after the patient is able to perform a single-leg hop test without any pain [3]. Other indications for nonsurgical management include the pre-existing insensate foot, minimal to no ambulatory ability or inflammatory arthritis. Patients should be made aware that conservative treatment with a cast or boot is associated with a high rate of loss of reduction [8, 11, 21–26]. Crates and coworkers, looking at non-operative treatment of these subtle Lisfranc injuries, noted that these injuries had a failure rate of 56% (20/36) [10].

Operative Management

Open Reduction and Internal Fixation and Primary Arthrodesis

The indications for operative management are signs of instability, with open reduction and internal fixation (ORIF) being the gold standard. A study on 28 patients treated with ORIF and screws or K-wires found that in the ORIF group, anatomic reduction was more commonly achieved and had higher AOFAS scores (89.6 vs. 74.3) compared with closed reduction. In this same study, all patients with screws and 87.7% of the K-wire fixation achieved anatomic reduction [27]. There is a great deal of disagreement surrounding the role of CRPP as definitive fixation, and thus, CRPP is better utilized as staged treatment [personal communication, Sanders, R.].

Primary arthrodesis is another viable option for open treatment. The common indications for primary arthrodesis are severe fracture of the joint complex involving articular cartilage, previously failed ORIF, chronic injuries with severe degenerative joint disease, fractures leading to persistent pain or disability, the presence of a benign bone tumor, and the presence of any disorder causing cystic bone changes [28].

It is debated whether an attempt of open reduction and internal fixation should be performed initially or whether primary arthrodesis is a better treatment plan. A meta-analysis by Smith and colleagues failed to show a superior outcome between arthrodesis and ORIF although ORIF was associated with a higher incidence of secondary surgeries. It is believed that this lack of difference in outcomes is due to high anatomic reduction rates between both methods [29]. A systematic review by Sheibani-Rad and colleagues found that 1 year post injury, arthrodesis had slightly better functional outcomes than ORIF per AOFAS scores [30]. Some studies have shown that arthrodesis is the preferred treatment when the injury is primarily ligamentous. Coetzee and colleagues, looking at ligamentous Lisfranc injuries, reported higher AOFAS scores, less secondary operations, and higher return to pre-injury activity in primary arthrodesis [31]. Henning and colleagues found that the only significant difference between ORIF and primary arthrodesis was the significantly higher rate of secondary procedures with ORIF [32]. Mulier and colleagues had similar anatomic reduction rates between groups (67% PA and 75% ORIF). The Baltimore painful foot score in the ORIF group was higher (less pain) than the primary arthrodesis group. One main difference found in the study was that stiffness of the foot, loss of metatarsal arch, and sympathetic dystrophy occurred more frequently in the arthrodesis group [33]. Regardless of surgical treatment method, patients must understand that oftentimes, even with perfect surgical care, some patients will not return to pre-injury level of function.

Closed Reduction and Percutaneous Pinning

Closed reduction and percutaneous pinning (CRPP) may be the only option in the high-risk patient population in order to limit devitalization of the soft tissue envelope [9]. CRPP is effective in the management of more simple Lisfranc injuries [34]. One indication is a statically reduced Lisfranc joint but dynamic instability with abduction stress testing [3]. When percutaneous fixation is used correctly, it has been shown to be just as effective as open reduction and internal fixation. Perugia found that after treatment with CRPP, the mean AOFAS score was 81.0 ± 13.5 and recognized that outcomes were significantly better in combined fracture dislocations compared to purely ligamentous dislocations [35]. When choosing between CRPP with K-wire fixation and ORIF with screw fixation, CRPP with K-wires provides less trauma than ORIF to the soft tissues and a more physiologic joint during the healing process. The main disadvantages of K-wire fixation include migration, pin tract infection, and less rigid stabilization [36]. Blanco and associates believed that pin migration can be prevented by bending the K-wires out of the skin and incorporating the K-wires into the plaster cast [37]. Other studies have seen significantly worse outcomes. Korres and associates looking at 16 Lisfranc injuries treated by percutaneous fixation with K-wires had 50% of patients develop post-traumatic arthritis with all those non-anatomically reduced fractures developing post-traumatic osteoarthritis and higher AOFAS scores in the anatomic reduction group [38]. A study of 28 patients treated with screws or K-wires found that anatomic reduction was more commonly achieved and AOFAS scores (89.6 vs. 74.3) were higher in the ORIF group. In this same study, all patients with screws and 87.7% of those with K-wire fixation achieved anatomic reduction [27]. There is a great deal of disagreement surrounding the role of CRPP as definitive fixation, and thus, CRPP is better utilized as staged treatment [personal communication, Sanders, R.].

External Fixation

External fixation is a viable option in diabetic patients with risk factors for skin necrosis and peripheral vascular disease impairing wound healing. Levitt and associates acknowledge the role of external fixation as a treatment option to avoid extensive soft tissue compromise in patients with significant peripheral neuropathy to maintain long-term stability of the midfoot [39]. External fixation can also be used with crush injuries but is associated with high morbidity even in the best of circumstances [40].

Literature Inconsistencies

The major challenge throughout the literature addressing treatment of Lisfranc injuries is the lack of randomized prospective controlled trials. The majority of the evidence is driven by retrospective cohort studies or prospective cohorts. Larger prospective randomized data are needed to better guide decision-making.

Evidentiary Table and Selection of Treatment Method

The main studies important in the treatment of ST's injury are noted in Table 28.1 [31, 32, 42, 48]. Based on the literature, the authors believe that open reduction and internal fixation will result in the most favorable outcome.

Definitive Treatment Plan

The overall goal of treatment regardless of the severity of the injury is to restore anatomic joint alignment. The authors prefer to perform open reduction and internal fixation with the patient in the supine position. The entire leg from the knee down is prepped and draped in a sterile

Table 28.1 Evidentiary table: A summary of the quality of evidence for Lisfranc fractures

Author (year)	Description	Summary of results	Level of evidence
Rammelt et al. (2008) [48]	Comparative cohort study	40 patients were followed for an average of 36 months. Mean AOFAS scores were 81.4 in the 20 with primary ORIF and 71.8 after corrective arthrodesis, concluding that primary open reduction and internal fixation lead to improved functional results, earlier return to work, and greater patient satisfaction compared to the delayed arthrodesis group	II
Henning et al. (2009) [32]	Prospective randomized study	32 fractures or fracture dislocations were followed for 24 months. The rate of planned and unplanned secondary procedures including screw removal and secondary arthrodesis was 78.6% in the ORIF group and 16.7% in the primary arthrodesis group	II
Kuo et al. (2000) [42]	Retrospective	48 patients treated with ORIF had an average AOFAS score of 77. Points lost were due to mild pain, decreased recreational function, and orthotic requirement. 25% of patients had post-traumatic osteoarthritis, with half of those requiring arthrodesis. Anatomic reduction was a significant predictor of good outcome. Pure ligamentous injuries had worse outcomes compared to osseous injuries	III
Ly et al. (2006) [31]	Prospective randomized study	41 pure ligamentous injuries treated with either ORIF or primary arthrodesis. 18/20 in ORIF group achieved anatomic reduction compared to 20/21 in primary arthrodesis group. AOFAS scores in the ORIF were 68.6 compared to 88 in primary arthrodesis, concluding that pure ligamentous injuries are best treated with primary arthrodesis	II

fashion. A sterile tourniquet is applied and inflated after exsanguination. A triangle is placed under the knee to keep the foot in the plantigrade position [41]. When access to all three columns of the midfoot is needed, two dorsal longitudinal incisions are made. The medial incision is made between the first and second metatarsal, just medial to the extensor hallucis longus tendon, exposing the medial and middle columns. The lateral incision is made between the third and fourth interspace providing access to the lateral column. After subperiosteal exposure is complete, removal of any interposed bone, cartilage, or soft tissue is performed. The medial column is reduced first, and the lateral column is reduced last. To perform the reduction, a large clamp with one limb of the clamp is placed on the medial aspect of the medial cuneiform and the other limb of the clamp placed on the lateral aspect of the base of the second metatarsal. Stability of the reduction is then tested with the clamp in place. Guidewires are placed from the base of the first metatarsal to the first cuneiform. This is also performed on the second ray. If needed, another screw can be placed between the cuneiforms. Weight bearing is restricted for 6 weeks [6].

Predicting Long-Term Outcome

Even in the best circumstances, the patient should understand that return to pre-injury level is unlikely. Radiographic evidence of post-traumatic degenerative disease is common although it does not necessarily correlate with poor clinical outcome.

Injury to the articular surface and restoration of anatomic alignment are the best predictors of long-term outcome [42]. Good to excellent results have been reported with anatomic alignment in 50% to 90% of cases compared with 17% to 30% of patients with non-anatomic alignment [8, 43–45]. Other studies have shown that malalignment leads to symptomatic degenerative osteoarthritis in over half of cases [46].

Time of fixation affects long-term outcome as well. A study of Tarczynska and associates found that those treated 6 months post injury could not effortlessly stand or walk on their toes and outer feet margins. Secondary osteoarthritic changes were seen both in the involved joint and the remaining non-injured parts of the Lisfranc joint as well as the tarsal joints in all patients [47]. Rammelt and associates concluded that ORIF at the time of the injury leads to better functional results compared to delayed arthrodesis [48]. Henning and coworkers found that treatment after 3 months post-injury lead to decreased physical function and increased disability with the main cause of delayed treatment being lack of recognition of the initial injury [32]. Komenda and coworkers determined that the most common cause of intractable pain at the TMT joint was not identifying the extent of the injury at the time of initial examination leading to inadequate reduction [24].

Stabilization and rigid anatomic fixation produce the most favorable outcomes with purely ligamentous injuries faring worse than combined ligamentous and osseous injuries [46]. Bicolumnar injuries had worse outcomes than medial or lateral column injuries [49]. Mayerson and coworkers found that direct injuries and crush injuries had poorer outcomes compared to indirect injuries [8]. An outcome study by Dubois-Ferriere following 61 surgically treated Lisfranc injuries 2–24 years posttreatment found that 13 (21%) of the followed patients had to change physical activity due to pain, 39 wore regular shoes, 19 had inserts in their shoes, and 3 wore modified shoes, although all patients in the study were able to walk greater than 6 blocks without any trouble [45].

In summary, Lisfranc injuries can be devastating with return to pre-injury activity level unlikely. When treating these injuries, anatomic reduction and rigid fixation are important factors that affect prognosis.

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Part VII

Polytrauma, Infection, and Perioperative Management of the Orthopedic Trauma Patient

29 Timing of Treatment in the Multiply Injured Patient

Kevin D. Phelps, Laurence B. Kempton, and Michael J. Bosse

RJ: A 19-Year-Old Male with Multiple Injuries

Case Presentation

RJ is a 19-year-old male presenting to the emergency department after a high-speed motorcycle collision. On primary survey in the emergency room trauma bay, the patient is hemodynamically unstable with a blood pressure of 85/50, heart rate of 110 beats/min, respiratory rate of 35 breaths/min, and oxygen saturation of 70% with 100% inspired oxygen. The patient is immediately intubated. On secondary survey there is an obvious deformity of the left femoral shaft and the left forearm. His past medical history, medications, and allergies are unknown.

Computed tomography (CT) of the chest, abdomen, and pelvis demonstrates a liver laceration and a left pneumothorax for which a chest tube is placed.

On physical exam, the patient has weak but palpable pulses in all four extremities. The patient's left upper extremity has an obvious closed deformity in the mid-forearm. Compartments in the forearm are soft, and no open wounds are noted. Examination of the left lower extremity demonstrates a swollen left thigh with soft compartments. There is a 4-cm open wound over the lateral aspect of the femur draining blood. There is an obvious deformity of the thigh just above the knee.

Admission laboratory values:

Hematocrit: 22% (Hgb ≈ 7 g/dL)
Platelets: 50,000 cells/mL
pH: 7.28
Bicarb: 21 mEq/L
Base excess: −7.7 mEq/L
Lactate: 4

Radiographs of the femur and forearm are shown in Fig. 29.1a–e.

Interpretation of Clinical Presentation

The patient's physical exam and laboratory values are consistent with hemorrhagic shock and associated metabolic acidosis. His exam and radiographs demonstrate an open femur fracture and a closed both-bone forearm fracture. Open

K. D. Phelps (✉) · M. J. Bosse
Department of Orthopedic Surgery, Carolinas Medical Center, Charlotte, NC, USA
e-mail: kevin.d.phelps@gmail.com

L. B. Kempton
Indiana University School of Medicine, Department of Orthopedic Surgery, IU Health Methodist Hospital, Indianapolis, IN, USA

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Fig. 29.1 (**a**) AP radiograph femur. (**b**) Lateral radiograph femur. (**c**) AP radiograph hip. (**d**) AP radiograph forearm. (**e**) Lateral radiograph forearm

femoral fractures are classified as Gustilo and Anderson type III [1] injuries due to the amount of energy and subsequent soft tissue stripping that are required to create the open wound. Finally, considering his low platelet count and the amount of blood volume that EMS providers have likely replaced with crystalloid, colloid, and/or packed red blood cells (PRBCs), he is coagulopathic.

Given the patient's tachycardia, hypotension, tachypnea, and mental status, he has likely lost at least 30–40% of his blood volume [2]. The general surgery trauma team, in conjunction with the emergency department staff, should aggressively resuscitate the patient with fluids and blood products including PRBC, platelets, and fresh frozen plasma (FFP) in order to treat both the hypovolemia and the coagulopathy. The orthopedic team can provide valuable insight into the amount of blood loss to be expected from these injuries. Protocols governing administered ratios for these products vary by institution, but there have been recent studies advocating a 1:1:1 ratio of PRBCs, platelets, and FFP [3–5].

Depending on the patient's response to resuscitation and the general surgery team's interpretation of the CT scan findings, they will decide whether to take the patient directly to the operating room themselves, admit him to the intensive care unit (ICU), or declare him stable enough for orthopedic operative intervention. From an orthopedic standpoint, injuries that might benefit from early intervention (not necessarily urgent) include the type III open femoral fracture that needs debridement and stabilization. Factors that favor delaying operative intervention include the patient's hypovolemia, end-organ hypoperfusion, and coagulopathy.

The both-bone forearm fracture will eventually need operative fixation, and a detailed discussion of options is beyond the scope of this chapter. Considering the patient's current status, there is no role for immediate operative treatment of the forearm, and provisional stabilization in a splint should be performed acutely. Suspicion for forearm compartment syndrome should remain high over the next few days, and frequent neurovascular checks should be performed, or if the patient remains obtunded or sedated, the treating clinician should have a low threshold for checking compartment pressures.

Declaration of Specific Diagnoses

RJ is a 19-year-old male whose high-energy collision has caused pulmonary and hepatic injuries, a closed left both-bone forearm fracture, and an open left femoral shaft fracture, all of which have contributed to hemodynamic instability, hypovolemic shock, and likely coagulopathy.

Brainstorming: What Are the Treatment Goals and Options?

Acute treatment goals consist of:

1. Resuscitation to restore end-organ perfusion
2. Reversal of the coagulopathy
3. Timely debridement of the open femoral fracture
4. Stabilization of the femoral fracture
5. Provisional stabilization of the forearm fracture (planning for delayed definitive fixation)

Treatment options include:

1. Proceeding immediately to the operating room for debridement and either provisional or definitive stabilization of the open femur fracture
2. Waiting until hemodynamic stability and resuscitation parameters improve before operative intervention with provisional bedside irrigation and gross debridement of the open fracture, application of a clean dressing, and stabilization of the femoral fracture with skeletal traction, cutaneous traction, a bedside external fixator, or a speed splint for the first 24 h
3. Definitive fixation options include:
   (a) Intramedullary nail fixation
      (i) Reamed nail
      (ii) Standard flexible reamers
      (iii) Reamer irrigator aspirator (RIA, Synthes, Paoli, PA)
      (iv) Unreamed nail
   (b) Plate fixation

Evaluation of the Literature

The first edition of this book presented a literature search of relevant articles published from 1975 until 2011. A PubMed search was performed for articles published using the following phrasing: ("femur fracture" pulmonary) or ("femur fracture" mortality) or ("femur fracture" "respiratory distress") or ("femur fracture" "fat embolism") or (femur "respiratory distress") or (femur "fat embolism") or ("damage control orthopedics".) or ("early total care") or ("early appropriate care"). This revealed 34 citations from which we found eight relevant articles to review. Bibliographies from these articles were also reviewed, and relevant articles were added to our list of sources. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Timing of Femoral Fixation, Mortality, and Fat Embolism Syndrome/Adult Respiratory Distress Syndrome

There have been several retrospective clinical studies examining the relationship between the timing of femoral fracture fixation and the associated risks of mortality and pulmonary complications. Three eras of thinking have emerged as a result of publications over time: early total care, damage control orthopedics (DCO), and early appropriate care.

Early publications [6–11] suggested that patients with prompt definitive treatment may have improved outcomes, and this led to widespread adoption of "early total care" as the standard of care. These early studies were largely retrospective in nature, typically involved treatment of less severely injured patients in the early intervention groups, and were unable to control for known confounding factors such as severity of overall patient injury. In addition, the prospective randomized study by Bone and colleagues [8] that was often cited in the early 1990s failed to find significance for improvement of any clinical parameter in the early intervention group. In retrospect, the lack of statistically significant results and disparate groups among studies should have prompted further investigation prior to application of the "early total care" model to all patients. Unfortunately, adoption of early total care as the standard resulted in many unexpected complications including pulmonary issues and multiple-organ failure.

Concerns over increased complications of immediate fixation in patients with associated lung [12] and head [13, 14] injuries, along with an improved understanding of the physiologic dangers of early aggressive orthopedic intervention, led to the concept of "damage control orthopedics". Damage control orthopedics aims to temporize patients by achieving early fracture stabilization while postponing definitive fixation in an effort to avoid the effects of an additional physiologic insult during a window when the patient has a labile physiologic status [15, 16]. Scalea and colleagues [16] performed a retrospective review of 43 patients with femur fractures initially treated with external fixation compared to 284 patients treated with primary intramedullary nailing of the femur. Patients were only followed until the end of their index hospital admission. As expected, those patients that received external fixation were more severely injured (ISS 26.8 vs 16.8), required more fluid and blood within the first 24 h of admission, and had lower Glasgow Coma Scale scores than those treated with primary intramedullary nailing. Because of this, the patients in the external fixation had longer stays in the ICU, longer hospital admissions, and a higher mortality rate. They found that external fixation was rapid, associated with minimal complications, led to negligible blood loss, and was readily followed by intramedullary nailing when patients were more stable.

Lefaivre and colleagues [17] reviewed 90,510 patients from trauma registries at two Level I trauma centers that included 2027 femur fracture cases. The presence of a femoral fracture was independently predictive for mortality (odds ratio 1.606) and adult respiratory distress syndrome (ARDS) (odds ratio 2.129). Additionally, they found that time to surgery of <8 h was predictive for mortality compared to 8–24 h (odds ratio 7.14). There was a statistically nonsignificant trend toward higher risk of ARDS with fixation after 24 h (odds ratio 1.537). Because the incidence of ARDS in femoral fractures was very low (1.43%), the authors concluded that a larger sample size might yield a statistically significant increase in ARDS with fixation after 24 h. Given the retrospective study design, confounding factors may have contributed to higher risk with fixation in <8 h. Patients fixed early may have been under-resuscitated at the time of surgery or were so severely injured that the general surgery team took them for operative intervention immediately after arrival and definitive fixation was performed concomitantly.

More recently, the concept of "early appropriate care" has been introduced and investigated with multiple studies [18–29]. The impetus behind this concept is to characterize more accurately the patients that are amenable to early stabilization of musculoskeletal injuries that primarily limit mobilization (femur, pelvis, acetabulum, and spine injuries). Nahm and colleagues [27] reviewed the outcome of 750 polytrauma patients (average ISS of 23.7) with femur fractures treated between 1999 and 2006. After adjusting for age and ISS, early definitive stabilization (within 24 h of injury) of femur fractures (with ISS ≥18) was associated with fewer complications than delayed stabilization (18.9% vs. 42.9%, $p < 0.037$) and also with shorter hospital stays, intensive care unit stays, and ventilator days ($p < 0.001$). Severe abdominal injuries were found to be associated with more complications than head or chest injuries (44% vs. 40.9%, $p = 0.68$, and 34.4%, $p = 0.024$, respectively) and were an independent risk factor for complications ($p < 0.0001$). In this case series, the authors frequently provided limited definitive treatment of non-femoral musculoskeletal injuries at the initial operative session rather than providing early total care. There were no stated objective metrics of resuscitation required before definitive femoral fixation. Although the authors provide useful data regarding prognosis in an early appropriate care population, their lack of rigorous criteria defining which patients are ready for orthopedic operative treatment limits their ability to draw conclusions regarding treatment strategy.

Harvin and colleagues [28] performed a retrospective review of 1376 trauma patients who underwent early (1023 patients, <24 h) or late (344 patients, ≥24 h) femoral nailing. After controlling for anatomic and physiologic severity of injury using the ISS and the Revised Trauma Score (RTS), they found that early fixation was associated with a reduction in pulmonary complications (OR = 0.43), decrease in hospital length of stay (6 vs. 10 days, $p = 0.001$), fewer ventilator days, and lower hospital charges ($59,561 vs. $97,018, $p = 0.001$) when compared with delayed fixation. Mortality was also found to be lower in the early fixation group (0.4% vs. 1.7%, $p < 0.01$). A major limitation of this study was the exclusion of patients in extremis on admission and those who had pulmonary insult prior to fixation. These results represent outcomes in a relatively stable patient population treated at centers that subscribed to an early appropriate care philosophy. Therefore, as with previous similar retrospective studies, the early group was self-selecting as they were less severely injured than the late group. This inherently predisposed them to improved outcomes.

Nahm and Vallier [25] performed a systematic review to determine the impact of timing of definitive stabilization of femoral shaft fractures in the polytrauma patient on the incidence of ARDS, mortality rate, and hospital length of stay. A total of 38 studies were reviewed and were grouped into four categories: heterogeneous injuries with early versus delayed treatment (17 studies), heterogeneous injuries with early versus DCO (8 studies), head injury (13 studies), and chest injury (7 studies). Although one must be careful comparing the results of the various studies due to changes in critical care delivery over time, the authors found that most of the studies reported lower or equivalent ARDS and mortality rates in the early group compared to the delayed group with shorter hospital stays in the early group. The authors also noted that the defining criteria and incidence of ARDS were inconsistent between American and European studies.

In summary, multiple retrospective studies have concluded that fixation within 24 h of injury is associated with significantly fewer pulmonary complications compared to later fixation [7–10, 30–32]. These findings are difficult to interpret due to confounding factors such as associated injuries and unknown reasons for operative delays. Even with multivariate statistical analyses attempting to account for confounders, it is impossible to quantify and account for all the variables that influence clinical outcomes in such a heterogeneous population. Recent literature confirms the benefit of early definitive fixation of femur fractures but emphasizes the importance of clinical stability and appropriate resuscitation prior to surgical intervention to minimize the effect of the “second hit” in a physiologically fragile patient.

Timing of Femoral Fixation in the Multiply Injured Patient with Thoracic Trauma

Pape and colleagues [12] published one of the first studies suggesting that early fixation of femur fractures in patients with significant chest injuries may actually lead to worsened clinical outcomes. In the retrospective study, the authors divided 106 patients with femoral fractures and ISS > 18 into four groups based on the presence or absence of thoracic trauma (abbreviated injury scale ≥2) and fixation earlier or later than 24 h. They found a significantly higher incidence of ARDS in patients with thoracic trauma who were treated with intramedullary fixation within 24 h of injury (33%) compared to after 24 h (7.7%). The authors concluded that among patients with ISS > 18, the subset of patients with thoracic trauma should be treated with delayed fixation. However, this conclusion did not consider the higher incidence of bilateral pulmonary contusions in the early fixation group (29% versus 7.7%, $p = 0.069$). The likelihood of ARDS in the setting of bilateral pulmonary contusions was not analyzed.

In a similarly designed retrospective study, Charash and associates [10] considered multiple pulmonary complications [pneumonia, ARDS, fat embolism syndrome (FES), and pulmonary embolism] instead of just ARDS alone. They found that the overall pulmonary complication rate was significantly higher in the 25 patients with delayed intramedullary fixation compared to the 56 patients with early fixation even in the setting of thoracic trauma. Moreover, Boulanger and associates [33] retrospectively analyzed similar groups of patients with thoracic injury treated with intramedullary nailing in either ≤24 h (68 patients) or >24 h (15 patients). They found no significant differences in the incidence of ARDS, FES, pneumonia, pulmonary embolism, or multiple organ dysfunction syndrome between the two treatment groups or between the early treatment group and a matched case-control group of patients with thoracic injury and no femoral fracture. The former comparison is of limited use because few patients with femoral fractures were treated after 24 h, but the latter comparison suggests that pulmonary complications may have arisen independent of the femoral fractures and their treatment.

A retrospective study by Reynolds and associates [34] included a series of 424 patients with femoral fractures, 105 of whom had an ISS ≥18. In these patients, fixation was delayed in cases of prolonged resuscitation, hypothermia, coagulopathy, or other severe injuries. They found a gradual increase (not statistically significant) in pulmonary complications, with increased time to fixation in the patients with lower ISS. In the patients with ISS ≥18, there was a significantly higher incidence in postoperative pulmonary complications compared to patients with a lower ISS, and the timing of fracture fixation was not predictive for pulmonary complications. *The authors concluded that it is the severity of injury rather than timing of femoral fixation that places patients at risk for pulmonary complications.*

Brundage and associates [35] in a retrospective study of 1362 patients who sustained femoral shaft fractures divided patients into groups based on timing of fixation: <24, 24–48, 48–120, >120 h, and nonoperative treatment. They also looked at subsets of patients within this series including those with ISS >15 (674 patients) and those with thoracic trauma (328 patients). Among the patients with significant thoracic trauma (chest AIS >2) who underwent operative fixation, the mean ISS in the abovementioned groups ranged from 27 to 31 (no significant difference between groups). Within this subset, they found no difference in mortality between patients fixed in <24 h compared to those fixed later and significantly fewer cases of ARDS in patients fixed in <24 h compared to those fixed between 48 and 120 h. However, it must be noted that the institutional protocol applied to this population was early total care (fixation within 24 h) whenever physiological parameters would allow. Therefore, this study shares the same limitation as the aforementioned retrospective studies. Although the authors found no statistically significant difference in ISS between the <24-h group and the >24-h group, there were likely other factors (for which the ISS did not account) in the late fixation group that resulted in more hemodynamic instability requiring delayed fixation.

Morshed and associates [36] conducted the largest study addressing this issue by the use of the United States National Trauma Data Bank. Again, the study was a retrospective cohort, this time including 3069 patients with femoral fracture and ISS ≥15. They divided patients into groups based on time to fixation of 0–12, 12–24, 24–48, 48–120, and more than 120 h. They found that risk of mortality was significantly greater with fixation in less than 12 h compared to fixation at all other time points except 24–48 h. They also found that abdominal trauma was a significant predictor of increased mortality with fixation in less than 12 h. The authors suggested that the likely benefit to delayed fixation was possibly achieving preoperative resuscitation; however there were no data in the study to support this assertion.

Recent studies have continued to show similar results. Vallier and associates [18] developed a database of 1443 patients who had sustained high-energy trauma with subsequent fractures of the pelvis ($n = 291$), acetabulum ($n = 399$), spine ($n = 102$), and/or proximal or diaphyseal femur ($n = 851$) and constructed a model to predict complications and help identify those clinical conditions which would warrant delay of definitive fixation. The authors found that abnormal pH and base excess values, as well as those values that were slower to improve, were associated with increased pulmonary complications. Higher lactate values were also associated with pulmonary complications and were the strongest predictor of overall complications. As noted in previous studies, an associated chest injury was the strongest independent predictor of pulmonary complications. The authors emphasize the importance of acidosis on presentation, as correction of pH to >7.25 within 8 h was associated with fewer pulmonary complications. They proposed definitive management of unstable fractures of the femur or axial skeleton within 36 h if the patient has responded to resuscitation with lactate <4.0 mmol/L, pH >7.25, or base excess less than −5.5 mmol/L. A DCO strategy was recommended in the setting of persistent acidosis with continual assessment to determine timing of definitive care.

Vallier and associates [19] subsequently performed a retrospective review of 1005 trauma patients with ISS ≥ 18 with pelvis ($n = 259$), acetabulum ($n = 266$), proximal or diaphyseal femur ($n = 569$), and/or thoracolumbar spine ($n = 98$) fractures. Associated injuries of the chest ($n = 447$), abdomen ($n = 328$), and head ($n = 155$) were also present. Five hundred seventy-two patients underwent definitive surgery within 24 h (mean ISS 29.1) and 433 after 24 h (mean ISS 32.5). The early fixation group actually had a greater mean level of initial acidosis (7.32 vs. 7.34, $p = 0.004$) than the delayed group. After adjusting for ISS and age, the authors found that days in the intensive care unit (5.1 vs. 8.4 days, $p = 0.006$) and total hospital stay (10.5 vs. 14.3 days, $p = 0.001$) were lower with early fixation. The early fixation group also had fewer overall complications (24.0% vs. 35.8%, $p = 0.40$) and fewer cases of ARDS (1.7% vs. 5.3%, $p = 0.048$), pneumonia (8.6% vs. 15.2%, $p = 0.070$), and sepsis (1.7% vs. 5.3%, $p = 0.054$). As with other studies, the conclusions from this study are limited by the heterogeneity of injuries and the lack of a formal protocol with objective parameters to determine "readiness" for definitive fixation.

Timing of Femoral Fixation in the Setting of Hypoperfusion

Authors have also investigated the importance of preoperative resuscitation as an independent predictor of complications after femoral nailing. During the course of resuscitation with fluid and blood products, even after heart rate and blood pressure normalize, occult end-organ hypoperfusion can still be detected by markers such as elevated serum lactate, decreased urine output, poor oxygenation, and hypothermia. Prospective cohort studies have shown that time to lactate normalization following injury is predictive of morbidity and mortality [37, 38]. Abramson and associates [37] analyzed prospectively collected data from 76 consecutive multiple trauma ICU patients and found a significantly higher rate of survival with earlier lactate normalization to ≤2 mmol/L compared to later normalization ($p < 0.0001$). Specifically, there was a 100% survival rate for patients with lactate normalization in less than 24 h, a 77.8% survival rate between 24 h and 48 h, and a 13.6% survival rate after 48 h. Meregalli and associates [38] analyzed blood lactate levels from 44 consecutive postoperative ICU patients at 12 h, 24 h, and 48 h and found a significant decrease in blood lactate levels from baseline at 12 h in the survivors ($p < 0.05$) compared to nonsignificant changes with time in nonsurvivors.

O'Toole and associates [39] reviewed a series of 249 femoral nails in 227 patients with ISS ≥18. Their treatment algorithm included fluid and blood product resuscitation upon presentation and serial serum lactate values as a measure of resuscitation. Reamed intramedullary nailing was typically performed within 24 h of presentation, but it was delayed if necessary until lactate levels trended toward ≤2.5 mmol/L and the hemodynamic and ventilation parameters and intracranial pressures (ICP) were stable. In delayed cases (12%), external fixators were placed until the patient was stable enough to undergo definitive intramedullary nailing. As expected, they found significantly higher ISS in the delayed fixation group, which was likely a contributing cause to the 20% mortality in that group, and so comparisons between the early and delayed fixation groups were of little value. The authors concluded that their low rates of mortality (2%) and ARDS (1.5%) in the early fixation group demonstrated that their treatment algorithm using resuscitation markers and ICP was an effective way to select patients able to tolerate early intramedullary fixation.

Crowl and associates [40] retrospectively reviewed a series of 177 hemodynamically stable patients undergoing femoral nailing with measured preoperative lactate levels. Patients deemed to have preoperative occult hypoperfusion based on lactate levels ≥2.5 were at significantly higher risk for postoperative complications of all types. Patients of all ISS were included in this study, and preoperative ISS was similar between the two groups. Postoperative infection rate was significantly higher in the hypoperfused group (72% versus 28%).

Another retrospective study looking at the relationship between extent of resuscitation and complications after reamed femoral nailing was performed by Morshed and associates [41]. They measured preoperative venous serum bicarbonate levels 6 h, 12 h, and 24 h within femoral nailing and found that levels <24.7 mEq/L at all time points were significantly predictive for postoperative "pulmonary organ dysfunction" (POD) after statistically adjusting for age, ISS, and preoperative POD. Although this result does not support a relationship between under-resuscitation and more important outcomes such as ARDS and mortality, it does demonstrate a link between preoperative hypoperfusion and postoperative pulmonary function. This further supports the interdependence of all the above factors (timing of fixation, pulmonary injury, high ISS, and hypoperfusion), which explains how these factors may confound retrospective studies, leading to conflicting results.

Pape and coworkers [42] in a multicenter randomized prospective study analyzed outcomes in 165 patients with femoral fractures and a New Injury Severity Score ≥16. They compared patients undergoing early intramedullary nailing (<24 h) to those undergoing temporary external fixation with delayed nailing. In the subgroup of 121 patients classified as "stable" [43] upon arrival, they found no significant difference in pulmonary complications between early and delayed fixation other than increased ventilator time with delayed fixation. In the 44 patients classified as "borderline", there was a significantly higher risk of postoperative "acute lung injury" (ALI) in patients undergoing intramedullary nailing within 24 h. However, the clinical significance of ALI is not clear, and there was not an increased risk for other clinically significant outcomes such as ARDS, pneumonia, and sepsis. Although this study did not specifically examine markers of resuscitation, the surgeons making the determination of stable versus borderline condition likely did. Therefore, this study supports improved outcomes with delayed femoral fixation in under-resuscitated patients. Due to ethical considerations, more severely injured (unstable) patients were excluded from the study.

Nahm and coworkers [26] performed a retrospective study investigating the outcomes of a cohort of patients with femur and axial skeleton fractures that were fixed in either an early or delayed fashion. The patients were retrospectively risk-stratified into low-risk (pH ≥ 7.25, base excess ≥−5.5, lactate <4.0) or high-risk (pH <7.25, base excess <−5.5, lactate ≥4) groups by the early appropriate care protocol [18] and described as stable, borderline, unstable, or in extremis using a modified clinical grading system (CGS) [43, 44]. Of the patients analyzed, 515 met criteria for early appropriate care analysis, 96% of which qualified for the low-risk group. Fifty-one percent received definitive fixation within 24 h, while 49% received delayed intervention. Early fixation was associated with fewer complications in this group compared to delayed treatment (20% vs. 35%, $p < 0.001$). In the high-risk group, 73% received treatment within 24 h, and 27% received treatment more than 24 h after injury. No differences were found within the small high-risk cohort of the early appropriate care group when comparing early versus delayed fixation. In the mCGS group, early treatment was associated with fewer complications in the stable patients when compared with delayed treatment (8% vs. 19%, $p < 0.001$). This was also true for borderline patients (15% vs. 27%, $p = 0.002$). No differences in complications were seen when comparing early versus delayed fixation in the unstable patient group.

In a subsequent prospective study, Vallier and coworkers [21] reviewed their initial experience with adherence to the early appropriate care protocol (definitive fixation within 36 h in resuscitated patients) within their multidisciplinary group. They evaluated the outcomes of 305 consecutive patients with ISS ≥16 (mean 26.4) and fracture of the proximal or diaphyseal femur (n = 152), pelvic ring (n = 56), acetabulum (n = 44), and/or spine (n = 94). Two hundred fifty-one patients were treated according to the protocol (82%), and 54 patients (18%) were treated in a delayed fashion. Prior to implementation, 76% of patients had been treated in a delayed fashion. Surgeon choice was the primary reason for delay (67%) followed by intensivist choice (13%), operating room availability (7.4%), severe head injury (5.6%), patient choice (3.7%), or cardiac issues (3.7%). They noted that only 10% of patients were treated in a delayed fashion 2 years after implementation and emphasized the importance of teamwork among related specialties and hospital support. In a separate publication, Vallier and coworkers [20] showed that their early appropriate care model resulted in fewer complications (16.3% in patients fixed within 36 h vs. 33.3% in delayed patients) and shorter length of hospital and ICU stay (9.5 vs. 17.3 days and 4.4 vs. 11.6 days, respectively, both $p < 0.0001$).

Vallier and coworkers [22] further evaluated the effect of implementation of their early appropriate care protocol on hospital length of stay and revenue. In a prospective consecutive series of 253 patients, the authors found that delayed fracture care (n = 47) was associated with more ICU days (4.5 vs. 9.4 days) and total hospital days (9.4 vs. 15.3). They noted a mean loss of $6380 per delayed patient and facility collections decreasing by 5% with a complication. Overall, delayed fixation accounted for $300,000 more in actual costs during the study.

Another important issue in the multiply injured patient is the number of injuries to address at each surgical setting. To address this, Childs and coworkers [45] assessed the impact of single versus multiple procedures in the same surgical setting on complication rates and hospital length of stay. This prospective cohort study included 370 patients with high-energy fractures who underwent treatment according to the early appropriate care protocol. Definitive fracture fixation was performed concurrently with another (non-orthopedic) procedure in 147 patients. This group had a higher ISS (29.4 vs. 24.6, $p < 0.01$), more transfusions (8.9 U vs. 3.6 U, $p < 0.01$), and longer surgery (4:22 vs. 2:41, $p < 0.01$) than those patients undergoing fracture fixation only. There were no differences in complications between these groups. Compared to the staged procedure group, patients with multiple same session procedures had fewer complications (33% vs. 54%,

$p = 0.004$), fewer days of mechanical ventilation (4.00 vs. 6.83 days), shorter ICU stays (6.38 vs. 10.6 days), and shorter hospital length of stays (12.4 vs. 16.0 days). Although the study lacked specific criteria to determine whether a patient could undergo additional operative procedures under the same anesthetic, it does suggest that resuscitated, hemodynamically stable patients benefit from an early total care approach.

Weinberg and coworkers [46] assessed the relationship between postoperative complications and time required for resuscitation of metabolic acidosis in the setting of an early appropriate care model. They prospectively evaluated the complications in the 6-month postoperative period for 332 patients with major trauma (ISS ≥16) with operative orthopedic injuries. A lactate value and arterial blood gas analysis were obtained for all patients on admission and subsequently repeated at 8-h intervals until normalization to the early appropriate care resuscitation parameters (lactate <4.0 mmol/L, pH ≥ 7.25, or base excess ≥−5.5 mmol/L) had occurred. Sixty-six patients ultimately developed complications, which were independently associated with ISS and time to resuscitation. A 2.7-h increase in time to resuscitation was found to be equivalent to a 1-unit increase on the ISS with respect to the odds for sustaining a complication. The authors emphasize the need to correct acidosis in a timely fashion in an attempt to optimize patient outcomes.

Richards and coworkers [47] performed a retrospective study at three academic tertiary care trauma centers to evaluate the relationship between preoperative lactate levels and postoperative pulmonary complications in the setting of reamed intramedullary nailing of femur fractures treated with early fixation (within 24 h). Of the 414 patients identified, 294 (71%) had an admission lactate ≥2.5 mmol/L (median 3.7). There were no significant differences in pulmonary complications found between patients with an admission lactate ≥2.5 mmol/L compared to <2.5 mmol/L. One hundred eighty-four of 294 patients with elevated admission lactate also demonstrated an elevated preoperative lactate ≥2.5 mmol/L (median 2.8). No association was shown between preoperative lactate and ventilator days or pulmonary complications. After adjusting for GCS, age, chest AIS score, abdominal AIS, and admission glucose with a multivariable linear regression model, the admission lactate value was correlated with duration of mechanical ventilation ≥5 days. Logistical regression also revealed that the admission lactate value was associated with pulmonary complications (OR = 1.26) after controlling for age, admission GCS, chest AIS, abdominal AID, admission pulse, and admission glucose. Although the authors note that lactate remains an efficient and reliable marker of cellular metabolism and is useful in the evaluation of trauma patients with femur fractures, the study did not provide a feasible method for incorporation of lactate values into clinical practice.

Methods of Femoral Stabilization in the Multiply Injured Patient

Provisional Stabilization

Evidence to support the superiority of a specific temporary stabilization method over another is lacking. Scannell and coworkers [48] retrospectively reviewed 79 patients who underwent delayed reamed femoral nailing (>24 h) after temporization with either external fixation (19 patients) or skeletal traction (60 patients). There were no significant differences in ISS or time to definitive fixation between the two groups. The authors found no significant differences between the groups in rates of multiple measures of morbidity (including ARDS) or mortality. There was a significantly higher incidence of sepsis and length of stay in the external fixation group.

A prospective randomized study by Even and coworkers [49] compared the use of cutaneous (37 patients) versus skeletal (29 patients) traction in 66 femur fractures amenable to fixation within 24 h. Cutaneous traction demonstrated a significantly reduced time to application (24.3 vs. 57.1 min) when compared to skeletal traction. No differences between the groups were found in posttraction visual analog scale (VAS) for pain assessment, pain medicine requirements, or intraoperative fracture reduction time.

Concerns regarding traction pins are related to potential infection risks and ongoing knee issues. Austin and coworkers [50] performed a retrospective case-control study evaluating infection risks following placement of 169 extremity traction pins (85% placed at bedside). A single infection (knee septic arthritis) was noted in their cohort which was felt to be related to improper distal femoral pin placement. Infection rates at associated operative sites were not increased when compared to nationwide standards.

To assess knee function, Bumpass and coworkers [51] prospectively evaluated 120 patients who underwent placement of distal femoral traction pins (85 patients) or splinting (35 patients) for femoral fractures and compared subsequent knee dysfunction and pain between the groups. No significant differences were found in the Lysholm knee scores at 6-month postinjury, although VAS pain scores were significantly lower in the traction group. There were no infections, neurovascular injuries, or iatrogenic fractures in the traction pin group.

Reamed Nailing Versus Unreamed Nailing

Many studies have looked for mechanisms underlying the association between intramedullary fixation and pulmonary complications. In a series of reamed intramedullary nailing of 17 tibiae and 14 femora performed with continuous transesophageal echocardiography (TEE) of the right atrium, Pell and coworkers [52] found six patients with showers of small emboli (<10 mm) and four patients with large emboli (>10 mm) during reaming and nail placement. Pape and coworkers [53] found statistically significant decreases in oxygenation ratios (PaO_2/FIO_2) and increases in pulmonary artery pressure in 17 reamed femoral nails compared to 14 unreamed femoral nails. These studies were unable to draw conclusions about clinical outcomes.

Conversely, Norris and coworkers [54] used alveolar dead space to measure pulmonary function in a series of 50 reamed femoral nails and 30 unreamed or minimally reamed nails and found that alveolar dead space significantly increased with unreamed nailing compared to reamed nailing. Additionally, they found that alveolar dead space and ISS were significantly associated with postoperative pulmonary dysfunction. The combination of these two conclusions suggests that reaming the femoral canal is not an independent risk factor for postoperative pulmonary complications. Providing further support for this conclusion, the Canadian Orthopedic Trauma Society in a prospective, randomized, multicenter clinical trial, including 151 femoral shaft fractures randomized to unreamed nail treatment and 171 fractures randomized to reamed nail treatment, found only five patients with ARDS (three in the reamed group and two in the unreamed group) [55]. The difference in ARDS incidence between patients with reamed and unreamed femora was not statistically significant. They also found that thoracic injury, postoperative oxygenation ratios, and ISS were not predictive for ARDS development.

Duan and colleagues [56] subsequently performed a systematic review of the literature to determine the effects of reamed versus unreamed intramedullary nailing for femoral shaft fractures. The authors identified seven trials with 952 patients (965 fractures). When compared with unreamed nailing, reamed nailing was associated with a lower reoperation rate, lower nonunion rate, and lower delayed union rate. No significant differences were noted for implant failure, mortality, or ARDS.

RIA Versus Standard Reamer

The RIA has been proposed to be a possible method for minimizing embolization of marrow contents with the hope of preventing the "second hit" phenomenon to the lungs. As it reams the femoral canal, it flushes the canal with saline while simultaneously aspirating the fluid and intramedullary contents to prevent high intramedullary pressures from forcing the contents into the circulation. In a randomized controlled trial of 20 femoral nails comparing standard reamers to the RIA, Volgas and colleagues [57] found a nonsignificant trend toward less embolized material passing through the right atrium (on TEE examination) during reaming with the RIA versus standard reamers. However, there was a statistically significant trend toward less embolization during actual nail passage after using the RIA compared to using standard reamers.

Other studies have looked at markers of inflammation following RIA versus standard reaming with variable results [58–60]. Streubel and colleagues [61] performed a retrospective study of conventional reaming ($n = 66$) versus RIA ($n = 90$) and found no significant differences in pulmonary complications, healing rates, or deaths between the two groups. Wang and colleagues [62] performed an animal study to assess whether the RIA could reduce systemic embolic load compared with a standard reamer. Fifteen pigs in a simulated shock state underwent bilateral retrograde femoral reaming using either the RIA or standard reamer, cement pressurization of the femoral canals, and nailing using Steinmann pins. The RIA group showed higher values for mean arterial pressure, higher partial pressure of arterial oxygen, higher cardiac output (after cement injection), and lower pulmonary arterial pressure levels than the standard reamer group. The RIA also led to fewer fat emboli in the lungs as visualized with the use of Oil Red “O” staining techniques.

Miller et al. [63] also investigated the impact of reaming technique on fat emboli. They subjected 24 canines to unreamed nailing, sequential reamed nailing, or RIA-reamed nailing of both femora (eight dogs per group). The total embolic load passing through the carotid artery was 0.049 cc, 0.045 cc, and 0.013 cc for the unreamed, sequentially reamed, and RIA-reamed groups, respectively (no significant difference). The RIA group also had fewer large emboli, fewer particulate emboli in the brain, and less evidence of physiologic stress. The threshold of fat emboli that leads to neurologic sequelae is not known; the clinical relevance of these findings is therefore uncertain.

Despite various promising studies, the RIA has not been widely adopted for the treatment of acute femur fractures. Due to the low rates of morbidity and mortality associated with standard reamers using modern resuscitation protocols [17, 39], it is unlikely that any clinically significant benefit with the RIA will ever be found.

Intramedullary Versus Plate Fixation

As the above studies have shown, pressurization of the intramedullary canal during reaming and nail passage embolizes intramedullary contents to the lungs. Evidence is conflicting whether this compromises postoperative pulmonary function [53–55]. Because of this concern, plating of the femur instead of intramedullary nailing might prevent further insult to the lungs, which would be especially desirable in patients with pulmonary trauma. Bosse and colleagues [30] retrospectively reviewed a series of 453 femoral fractures in patients with ISS ≥ 17 who were treated with either plate fixation or intramedullary nailing. They found no difference in rates of ARDS, multiple-organ failure, pneumonia, pulmonary embolism, or mortality when comparing the two types of fixation whether concomitant thoracic trauma was present or not.

Literature Inconsistencies

Throughout the past several decades, the largest source of debate in regard to timing femoral fracture fixation has involved what preoperative factors best determine which patients should undergo early versus delayed definitive fixation (damage control orthopedics). The retrospective design of the vast majority of the studies surrounding this question has substantially contributed to the controversy by introducing confounding factors, that is, factors that affect both the group assignment and the outcome. The likelihood of mortality or pulmonary complications is multifactorial, and so it is extremely difficult (if not impossible) for any retrospective study to consider all contributing factors. Any retrospective study performed at a center that embraces the concept of early total care often results in comparison of unequal populations: a group of patients stable enough to receive early care and a group of unstable patients who must wait. The timing of definitive intervention for patients can also be system-dependent and related more to resource availability than stability and “readiness” of the patient. No matter how many variables are incorporated into a complex statistical analysis to adjust for measurable inequalities between groups, there will always be factors that are not considered and cannot be quantified. Additional studies are needed to better elucidate the parameters that allow us to best determine which patients can be definitively treated sooner.

A concept that has not been disproven since it was first accepted is that for euvolemic patients with an isolated femoral shaft fracture and no other injuries or hemodynamic concerns, earlier fixation results in a lower incidence of pulmonary complications, shorter length of hospital stay, earlier mobilization, and lower overall cost of treatment. Such patients should not be considered for a damage control protocol.

Evidentiary Table and Selection of Treatment Method

Table 29.1 [10, 18, 22, 30, 35, 39, 40, 45, 47–49, 55] lists the studies and level of evidence used for guiding RJ's treatment.

Definitive Treatment Plan

The patient's hemodynamic instability, coagulopathy, and acidosis with an elevated lactate indicate that he is currently under-resuscitated and has end-organ hypoperfusion. Therefore, based on the principles of early appropriate care, we would delay his definitive femoral fixation until he is more adequately resuscitated. The patient would have a provisional wound debridement at the bedside (i.e., removal of any superficial gross contamination and superficial irrigation of the wound) and would be placed into a clean dressing. A speed splint, skeletal traction, or cutaneous traction would then be placed at the bedside. If a speed splint or cutaneous traction was chosen, either would be converted to skeletal traction after approximately 24 h if the patient continued to remain too unstable for operative intervention. If the general surgery team decides that they need to do an exploratory laparotomy or other emergent operative procedure, we would plan to more formally debride the open fracture and potentially place an external fixator or traction pin in the same operative session, assuming that an extra 20–30 min in the operating room would not compromise his clinical status. If the patient were found to have a head injury with elevated ICP (not mentioned in the vignette), we would delay definitive fixation until the ICP stabilizes.

In conjunction with the ICU critical care team, we would monitor signs of adequate resuscitation including lactate levels, base excess, pH, heart rate, blood pressure, urine output, temperature, oxygenation, and ventilator status. Once these parameters normalize, we would take the patient to the operating room for debridement of the open fracture (if not already performed) and placement of a reamed intramedullary nail using standard reamers. If the patient remained stable following intramedullary nailing of his femur, we would then proceed with plating of his both-bone forearm fracture. If laboratory values or physiologic parameters were becoming unfavorable following intramedullary nailing of the femur, we would leave the forearm fracture in a splint and return for definitive fixation in a staged fashion at a later date.

Predicting Outcomes

To extrapolate data from the abovementioned studies to this patient, we must first assume that his hemodynamic instability and hypoperfusion will be reversed sufficiently to allow for intramedullary nailing. The likelihood of postoperative mortality and pulmonary complications depends on how soon he can be adequately resuscitated (as determined by his serum lactate levels) and subsequently treated with intramedullary nailing. Given RJ's spectrum of injuries and ISS, and assuming that he has no unidentified injuries not mentioned in the vignette and can undergo definitive intramedullary nailing within 24–48 h, his likelihood of mortality in the postoperative period is approximately 1–5% [8, 12, 30, 35, 36, 48, 55]. His likelihood of postoperative ARDS is approximately 3–12% [10, 12, 30, 35, 39, 48,

Table 29.1 Evidentiary table: A summary of the quality of evidence for early versus delayed intramedullary (IM) nailing of femoral shaft fractures in multiply injured patients

Author (year)	Description	Summary of results	Level of evidence
Vallier et al. (2013) [18]	Statistical model based on retrospective database	1443 patients with femur and axial skeleton fractures treated surgically. Lactate values were higher, while pH and base excess levels were lower with pneumonia and other pulmonary complications. Lactate was the strongest predictor of complications while chest injury most strongly predicted pulmonary complication	II
Vallier et al. (2016) [22]	Prospective consecutive series	253 patients with femur and axial skeleton fractures treated surgically. Delayed fixation was associated with more complications and loss of revenue for the hospital system	IV
Childs et al. (2016) [45]	Prospective, cohort	370 patients with high-energy fractures of the femur and axial skeleton treated with early appropriate care protocol. Definitive fixation in the same setting as another (non-orthopedic) procedure led to lower complication rates, ventilation time, ICU stay, and hospital length of stay	II
Richards et al. (2016) [47]	Retrospective	414 patients who underwent reamed intramedullary nailing within 24 h. Mean admission lactate of 3.7 mmol/L was associated with duration of mechanical ventilation ≥5 days. There was no association between preoperative lactate and pulmonary complications	III
Bosse et al. (1997) [30]	Multicenter, retrospective cohort study	453 femur fractures (ISS ≥17) treated with IM nail or plate had no difference in rates of pulmonary complications or mortality between the two groups. Also, no difference in results with or without thoracic trauma	III
Brundage et al. (2002) [35]	Retrospective cohort study	328 femoral fractures with thoracic trauma. Those with IM nail within 24 h had significantly fewer cases of ARDS compared to those fixed after 48 h. Mortality no different between the two groups	III
Canadian Orthopedic Trauma Society (2006) [55]	Prospective, randomized, multicenter trial	322 femoral shaft fractures treated with either reamed or unreamed IM nail. One hundred nine patients with ISS ≥18. Four deaths and five cases of ARDS. No difference in ARDS between the groups both for high and low ISS	I
Charash et al. (1994) [10]	Retrospective cohort study	56 femoral fractures with IM nail before 24 h versus 25 fractures with IM nail after 24 h. All patients with ISS >18. Pulmonary complications significantly more common in the late fixation group with and without thoracic trauma	III
Crowl et al. (2000) [40]	Retrospective cohort study	177 hemodynamically stable patients undergoing femoral nailing. Preoperative lactate levels ≥2.5 mmol/L were at significantly higher risk for postoperative complications	III
O'Toole et al. (2009) [39]	Retrospective cohort study	227 patients with ISS >18 treated with a protocol of lactate levels trending to ≤2.5 mmol/L before femoral IM nail fixation of fracture. Overall mortality was 2%, and ARDS was 1.5% in fractures that could be fixed within 24 h. These rates were lower than prior studies	III
Even et al. (2012) [49]	Prospective randomized trial	65 patients with 66 femur fractures randomized to skeletal or cutaneous traction. Cutaneous traction resulted in a reduced time to application with no complications, changes in operative time, or differences in VAS scores/narcotic use	II
Scannell et al. (2010) [48]	Retrospective cohort study	60 femoral fractures temporized with skeletal traction versus 19 temporized with external fixation before definitive reamed nailing after 24 h. No difference in ARDS or mortality between the groups	III

55]. If his lactate levels do not normalize within 24–48 h, his risk of mortality increases to approximately 11% [39].

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30 DVT Prophylaxis in Orthopedic Trauma

Keith D. Baldwin, Surena Namdari, Jeffrey Zhao, and Samir Mehta

KW: A 45-Year-Old Male with a Transverse Posterior Wall Acetabular Fracture and Femur Fracture

Case Presentation

KW is a 45-year-old man who was a restrained passenger in a high-speed motor vehicle accident (MVA). He has been hospitalized 5 days and underwent open reduction and internal fixation of his acetabular fracture 2 days ago and intramedullary nailing of his left femur 4 days ago. His other injuries include a very small subdural hematoma (SDH), which has been stable and is being followed by neurosurgery consultants.

His past medical history is negative. He takes no medications and has no allergies. He is a smoker.

On physical exam, the patient is awake and alert and in no acute distress. He is hemodynamically stable. His wounds are clean, and he is neurologically and neurovascularly intact throughout.

Radiographs of the pelvis and left femur are demonstrated in Fig. 30.1a–c.

There is debate regarding the most effective means of venous thromboembolism (VTE) prophylaxis in this clinical setting.

Interpretation of the Clinical Presentation

This patient has suffered serious orthopedic injuries in addition to a SDH, which mandates a thoughtful approach to VTE prophylaxis in order to maximize benefit and minimize complications. Unfortunately, the patient has both a very high risk of VTE accompanied by an injury (SDH) that precludes aggressive pharmacologic anticoagulation, a commonly used and effective means of VTE prophylaxis.

The EAST (Eastern Association for the Surgery of Trauma) first published VTE prophylaxis guidelines for the management of patients who have sustained severe trauma in 1998 and then updated these guidelines in 2002 [1]. This group conducted a systematic review of the

K. D. Baldwin
Childrens Hospital of Philadelphia, Department of Orthopedics, University of Pennsylvania, Philadelphia, PA, USA

S. Namdari
Rothman Institute and Department of Orthopaedic Surgery, Thomas Jefferson University, Philadelphia, PA, USA

J. Zhao
Northwestern Medicine, Northwestern University Feinberg School of Medicine, Chicago, IL, USA

S. Mehta (✉)
Penn Presbyterian Medical Center, University of Pennsylvania, Department of Orthopedic Surgery, Philadelphia, PA, USA
e-mail: Samir.mehta@uphs.upenn.edu

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Fig. 30.1 (**a**) AP radiograph pelvis. (**b**) AP radiograph femur. (**c**) Lateral radiograph femur

literature which investigated risk factors for VTE and critically evaluated modalities for VTE prophylaxis [1]. This group's meta-analysis of 73 studies showed that the only factor which significantly increased the risk of VTE was spinal fracture and spinal cord injury [1]. Other traditional risk factors such as increasing Injury Severity Score (ISS), blood transfusion, pelvic fractures, long bone fractures, and head injuries were not found to be associated with VTE risk in this meta-analysis [1].

Several single-institution studies, however, have shown that pelvic fractures, particularly those involving the posterior pelvis, confer a higher risk of VTE [2–4]. Specifically, Knudson and colleagues found in two studies of 400 and 487 trauma patients that pelvic fractures conferred a higher risk of VTE. This pair of studies also found that lower extremity fractures in patients of age greater than 30 years, and immobilization greater than 3 days conferred increased risk of VTE. Similarly, others have shown that injuries of the lower extremity long bones are associated with greater rates of symptomatic VTE [2–7]. A pair of studies by Geerts and colleagues reviewed 349 and 265 patients with major trauma and found that lower extremity long bone fractures (femur and tibia), spinal cord injury, older age, and need for blood transfusion to be risk factors for VTE as detected by venography. In a recent meta-analysis, Tan and colleagues found a five-fold increase in DVT for patients with fractures below the hip and in patients with previous VTE [8]. Additionally, Upchurch and colleagues found a higher rate of VTE in patients with head injuries [3]. These authors looked at 66 trauma patients and found head injury, along with older age, lower extremity trauma, spinal cord injury, and pelvic fractures to be risk factors for thromboembolism. As noted above, increasing age has been cited by several authors as a risk factor for VTE [2, 9, 10]. The exact relationship between age and VTE has been difficult to elucidate because authors have used different cutoff points for "older age," making meta-analysis of this risk factor difficult if not impossible [1].

Frankel and colleagues presented an algorithm for assigning risk for VTE in polytrauma patients [11]. Their guidelines place a patient such as the one presented, with posterior pelvic ring injuries plus a long bone fracture, at "very high risk" for VTE. Under their treatment algorithm, these patients would receive low molecular weight heparin, sequential compression devices, weekly screening duplex examinations for DVT, and consideration of inferior vena cava (IVC) filter placement [11]. This algorithm was developed from the EAST meta-analysis. Level I recommendations from this meta-analysis state that spinal cord-injured patients are at high risk of VTE. Level II recommendations were that long bone fractures, increasing ISS, older age, pelvic fractures, and head injuries confer higher risk for VTE.

More recently, the American College of Chest Physicians (ACCP) published orthopedic VTE prophylaxis guidelines based on an independent meta-analysis and recommendations from an expert panel [12]. A patient undergoing "major orthopedic surgery" would receive a Grade 1B recommendation for 10–14 days of prophylaxis and a Grade 2B recommendation for suggested use of low molecular weight heparin over alternative pharmacologic agents. The guidelines also contain a Grade 2B recommendation for outpatient pharmacologic prophylaxis up to 35 days after surgery. The ACCP makes a Grade 2C recommendation against IVC filter placement, including for use with patients who have contraindications to pharmacologic and mechanical prophylaxis.

An interesting and not altogether uncommon problem is the patient who presents with a minor SDH and injuries that place the patient at elevated risk for VTE. A recent trial of 669 patients compared early (0–72 h) versus late (>72 h) thromboprophylaxis for trauma patients with traumatic brain injury [13]. These authors found no difference in the rate of progression of intracranial hemorrhage between the early and late group [13]. They did notice an increased rate of VTE in the late group, though the difference was not statistically significant [13].

Declaration of Specific Diagnosis

Forty-five-year-old male status post-internal fixation of acetabular and femur fractures, with a SDH, who is at very high risk for VTE.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Prevent VTE, death, and postphlebitic complications.
2. Provide VTE prophylaxis while minimizing bleeding risk and wound complications.
3. Minimize secondary morbidity and secondary surgeries and anesthesia administration.
4. Return to normal life activities without permanent sequelae.

Treatment options:
Mechanical:

1. Foot pumps
2. Compression stockings
3. Sequential compression devices

Pharmacologic:

1. Aspirin
2. Warfarin
3. Low-dose unfractionated heparin (LDH)
4. Low molecular weight heparin (LMWH)
5. Factor Xa inhibitor

Surgical:

1. IVC filter placement

Evaluation of the Literature

To identify pertinent publications on VTE in the setting of significant orthopedic trauma, Medline and PubMed searches were performed. Keywords used were "venous thromboembolism" or "deep venous thrombosis" or "pulmonary embolism" and "orthopedic trauma" or "fracture surgery". Our search was from January 1975 to June 2011. Five hundred nine articles were identified using this search strategy. From this search, 132 articles of interest were identified. These articles were reviewed, and their references were further searched for other potential articles of interest. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

The following discussion involves an exploration of the mechanical, pharmacologic, and surgical options for VTE prophylaxis in this complex polytrauma patient.

Mechanical VTE Prophylaxis

Modalities of mechanical VTE prophylaxis include graduated compression stockings, sequential calf compression devices (SCD), and foot pumps. The principle advantages of these modalities are their ease of use, inexpensive nature, and minimal risks. The disadvantage is that they must be applied consistently to impart their prophylactic qualities, and patient compliance is problematic [14]. Cupitt performed a questionnaire of 26 neurosurgical units in the UK. Only 34% of units used intermittent compression devices, but 90% used some type of mechanical prophylaxis (most used compression stockings).

Foot pumps are useful when patients have extensive wounds on their lower extremities or external fixators that preclude the use of other mechanical prophylaxis devices. Stranks and colleagues conducted a randomized controlled trial of 82 elderly hip fracture patients, comparing foot pumps and no prophylaxis, and found that there was a significant increase in Doppler-detected proximal DVT in the control versus the foot pump group [15]. Interestingly, Santori and colleagues found in a randomized trial of 132 patients that foot pumps outperformed unfractionated heparin in a study of hip arthroplasty patients [16]. Spain and colleagues found in a non-randomized observational study of 184 trauma patients that foot pumps were roughly equivalent to SCDs in terms of VTE rates [17]. Fordyce and Ling conducted a randomized trial of 84 patients and determined that foot pumps were superior to TED stockings in preventing venographically detected DVT [18]. Overall, foot pumps are felt to be a suitable alternative to SCDs when these devices are impractical due to injury or external fixators [1].

SCDs are postulated to decrease VTE by stimulating fibrinolysis, an effect thought to be caused by sequential compression. These effects decay within minutes of discontinuing treatment, and so these devices must be worn consistently in order to be effective [19]. Jacobs and colleagues compared measures of blood clotting parameters (tissue plasminogen activator, plasminogen activator inhibitor, and euglobulin lysis time) in four control subjects and four subjects who had been treated with compression devices. They found that the effect of the compression devices on humoral clotting cascade proteins wore off almost instantly after discontinuation. In spite of their commonplace usage in the trauma setting, there have been relatively few studies examining the efficacy of SCDs in polytrauma patients. Knudson and colleagues prospectively studied 113 patients who received either low-dose heparin or SCDs and found no significant difference in the incidence of VTE [9]. Dennis and colleagues prospectively examined 395 trauma patients with an ISS greater than 9 and found no difference between SCD and low-dose heparin in preventing VTE. These authors did find that either strategy was superior to no prophylaxis [20]. In contrast, Velmahos and associates performed a meta-analysis of randomized and nonrandomized trials and found, using random effects modeling of five trials, that mechanical prophylaxis offered no benefit over no prophylaxis [21]. Interestingly, in spite of these data, a survey of the American College of Surgeons found that SCDs were the most commonly used method of prophylaxis (75% of respondents), with safety and efficacy cited as the primary reasons for usage [22]. In contrast, a 2013 Cochrane review meta-analysis of six randomized control trials found that mechanical prophylaxis in a general trauma setting reduced the risk of DVT but not PE or mortality [23]. The review also compared pharmacologic and mechanical prophylaxis modalities, finding that pharmacologic prophylaxis lowered the incidence of DVT compared to mechanical but increased the risk of minor bleeding [23].

Compression stockings are infrequently used as a sole method of prophylaxis. They have been shown to be inferior to foot pumps for prevention of VTE [18]. Many of the aforementioned reports advocate the usage of compression stockings in conjunction with SCD or other mechanoprophylaxis. However, this practice has not been rigorously investigated and is not currently considered to be the standard of care [1].

Pharmacologic Chemoprophylaxis

Many commercially available agents are available to provide VTE chemoprophylaxis. Among these agents are antiplatelet agents including aspirin, vitamin K antagonists such as warfarin, antithrombin III antagonists like LDH, and LMWH, and newer agents such as factor Xa inhibitors. All of these agents have mechanisms of action that interrupt the coagulation cascade at different points. The selection of a chemoprophylactic agent involves clinical decision-making regarding the agent's mechanism of action, clinical evidence regarding its efficacy, how quickly the effects can be reversed, and what side-effect profiles can be expected (most significant in the surgical population are bleeding and wound complications).

Due to issues with ease of reversibility and the unpredictable degree of prophylaxis conferred, aspirin, warfarin, and direct Xa inhibitors are not typically used in a trauma population. Aspirin is long-acting and could theoretically produce undesired bleeding in cases where trauma patients experience a planned or unplanned return to the operating room. As a result, aspirin represents a suboptimal choice for this population, in spite of its widespread use in elective orthopedic surgery. Warfarin, on the other hand, requires individualized dosing and takes several days to reach therapeutic levels, leaving the patient relatively unprotected in the early postsurgical or post-traumatic period. As a result, warfarin is infrequently used as a sole agent for the prevention of VTE in the orthopedic trauma patient, especially in the acute setting.

LDH, though used for several years in the trauma population, has fallen out of favor with trauma surgeons due to multiple studies that have questioned its efficacy in trauma patients. Although a meta-analysis of 29 randomized surgical trials found LDH to be effective in the prophylaxis of DVT in general surgery patients [24], the results in trauma patients have been not as promising. Upchurch and associates studied 66 trauma patients in the ICU and found no difference in the incidence of VTE between LDH and no prophylaxis [3]. A meta-analysis of four randomized controlled studies showed no difference between LDH and no prophylaxis [OR 0.97 (0.36, 2.97)] [21]. As such, LDH is rarely used by general and orthopedic trauma surgeons in high-risk patients in the modern setting.

LMWH has gained popularity in the trauma community as the prophylaxis of choice for orthopedic and general trauma patients. This popularity is owed in large part to the work of Geerts and associates [6] and Knudson and associates [2] in the late 1990s. Geerts and associates, in a randomized prospective comparative trial of 344 trauma patients, showed superiority of LMWH over LDH. Both interventions were safe, and although more bleeding complications were seen in the LMWH group (3.9% compared to 0.7%), the difference was not statistically significant [6]. If this is a true difference, the trial would have to be much larger to detect it (around 4000 per group). A recent randomized control trial and systemic meta-analysis by Beitland and associates found that LMWH reduced the risk of DVT compared to LDH in ICU patients [25, 26]. The Beitland and associates' review also determined that there was no difference in the risk of bleeding, mortality, or PE between the LMWH and LDH treatment groups [26].

Several studies have shown that LMWH is safe in both spinal cord- and head-injured patients [13, 27–29]. The DETECT trial, a retrospective cohort study of 135 patients, found that LMWH was associated with a low rate of major bleeds (6.9%) [27]. Phelan and associates performed a pilot randomized controlled trial comparing early enoxaparin administration to placebo in patients with small traumatic brain injuries and stable CT scans 24 h after injury [28]. Pharmacologic prophylaxis did not increase the risk of intracranial bleeding in this study. A meta-analysis by Galan and coworkers found that early enoxaparin prophylaxis in traumatic brain injury patients admitted within 72 h was more effective than late prophylaxis in reducing the incidence of DVT [29]. The most recent EAST guidelines report Level II recommendations for use of LMWH when patients have operatively treated pelvic fractures and complex lower extremity fractures or spinal cord injuries with paralysis [1].

Factor Xa inhibitors are relatively new pharmacologic agents that have been used for prevention of VTE in major orthopedic surgery. The early results of this approach are promising in terms of VTE reduction as compared to LMWH [30]. The PENTHIFRA trial, a randomized controlled trial of over 1600 hip fracture patients, noted favorable results of fondaparinux (a Factor Xa inhibitor) to LMWH in hip fracture patients with no increase in unfavorable outcomes (bleeding or infection) [30]. Lu and coworkers recently reported on a series of 87 patients with an average ISS of 18 who were treated with fondaparinux. They noted a reported lower rate of VTE compared to patients treated with only SCDs and cite a decreased concern for heparin-induced thrombocytopenia as a reason for increased interest in this medication [31]. Two recent studies by Tsiridis and coworkers found that fondaparinux prophylaxis decreased the risk of VTE compared to LMWH in patients with pelvic and acetabular fractures [32, 33]. In a small prospective study of 108 patients, 3% of LMWH recipients developed DVT, and 1% experienced fatal PE. No patients in the fondaparinux prophylaxis group developed DVT or PE [33]. Though the early results appear promising, there is insufficient evidence at this time to strongly recommend factor Xa inhibitors for the orthopedic polytrauma patient. The half-life of these agents ranges between 5 and 17 h, and specific reversal agents are currently under investigation. Current ACCP recommendations state that LMWH should be chosen over the factor Xa inhibitor fondaparinux for pharmacologic VTE prophylaxis.

Surgical Treatment

The only prophylactic surgical treatment available for VTE is placement of an IVC filter. These filters are typically placed percutaneously in the IVC by vascular or trauma surgeons using fluoroscopic guidance. Many of the filters currently used are retrievable and are removed at a later date. Although this method of prophylaxis has been available for years, there is still considerable debate regarding the indications for use of an IVC filter.

Though the EAST group recommends use of an IVC filter in the setting of ongoing VTE complications, the indications for the insertion of a "prophylactic" IVC filter are the subject of ongoing debate. Generally, IVC filters are strongly considered in patients who cannot be anticoagulated but are otherwise at high risk of VTE. This includes patients who have severe head injuries, multiple long bone fractures, and pelvic fractures which are complex or involve the posterior ring along with other long bone injuries or patients with complete or incomplete spinal cord injuries [1]. These indications were based on a study by Rogers and coworkers who found that in a series of 2525 total patients, 25 patients with these injuries accounted for 92% of the pulmonary emboli [34]. Retrievable IVC filters have made this treatment particularly appealing to trauma surgeons whose patients are at increased VTE risk for a finite period of time. Both the insertion and retrieval of these filters have been shown to be safe [35]. Johnson and coworkers placed 100 retrievable filters and followed them prospectively for 180 days. They had eight cases of PE after IVC placement and one case of filter migration; retrieval was successful in 92% of cases after an average of 61 days. However, to date there have been no large randomized controlled trials that show that IVC filters are more effective than no prophylaxis in preventing pulmonary embolism in very high-risk trauma patients. A 2014 meta-analysis of eight single-institution studies found a significant decrease in the incidence of PE and fatal PE but no change in mortality or DVT rates following IVC filter placement [36]. They labelled the strength of evidence as low due to high risks of potential bias identified in individual studies.

Literature Inconsistencies

The role of factor Xa inhibitors has yet to be defined, although the early results are encouraging in studies of hip fracture patients. Whether the addition of mechanoprophylaxis to chemoprophylaxis truly results in better VTE prophylaxis remains unresolved, though the preponderance of evidence in recent reviews is shifting toward a beneficial effect for combination prophylaxis. Barrera and coworkers found a decrease in risk of DVT after comparing mechanical and pharmacologic prophylaxis to pharmacologic alone, though the authors found statistical heterogeneity between trials in their comparison [23]. Newer clinical guidelines from the ACCP recommend concurrent use of chemical and mechanical prophylaxis for major orthopedic surgery unless a contraindication to prophylaxis exists.

Currently, the exact benefit of and indications for IVC filters in high-risk polytrauma patients remain undetermined. The state of evidence for these questions is relatively low at present.

Evidentiary Table and Selection of Treatment Method

The key studies pertinent to the treatment of KW are noted in Table 30.1 [2, 6, 21, 23, 34]. Based on the literature, the authors feel that the best evidence-based treatment in this case would be low molecular weight heparin along with a lower extremity compression device. Because the patient has an operatively treated acetabular fracture and a femur fracture, the patient falls into the "very high-risk" group; and as such, the authors also feel that he would be a candidate for an IVC filter. It is important to note that the use of compression devices in this clinical situation has been developed from evidence from elective orthopedic surgeries and the low rate of complications, rather than its effectiveness in clinical studies of polytrauma patients.

Definitive Treatment Plan

By the criteria of Frankel and coworkers, this patient falls into the "very high-risk" category and warrants aggressive prophylaxis with LMWH and SCDs [11]. This patient also had a SDH; however, Koehler and coworkers showed that early prophylaxis with LMWH results in no greater risk of SDH bleed progression than later prophylaxis [13]. As a result, we recommend LMWH once the SDH is noted to be stable and the risk of further bleeding is limited. Clearly,

Table 30.1 Evidentiary table: A summary of the quality of evidence for the treatment of a polytrauma patient at very high risk of thromboembolic complications

Author (year)	Description	Summary of results	Level of evidence
Barrera et al. (2013) [23]	Meta-analysis of randomized controlled trials	Decreased DVT risk (RR 0.55, 95% CI 0.34, 0.90) but no significant decrease in PE risk (RR 0.77, 95% CI 0.36, 1.66) or death (RR 0.74, 95% CI 0.27, 2.04) in 6 studies of 811 general trauma patients comparing mechanical prophylaxis versus no prophylaxis. Decreased DVT risk for combination mechanical and pharmacologic prophylaxis compared to pharmacologic prophylaxis alone. Significant heterogeneity among RCT studies	I
Geerts et al. (1996) [6]	Randomized prospective comparative study	344 patients ISS > 9, 136 received LDH, and 129 received LMWH. Outcome of proximal vein DVT measured by venogram: 15% in LDH group and 6% in LMWH group ($p = 0.012$)	I
Knudson et al. (1996) [2]	Prospective randomized controlled trial	372 high-risk trauma patients. 120 received LMWH, 199 received SCD, and 53 received A-V foot pumps. LMWH found to be superior in reducing DVT	I
Velmahos et al. (2000) [21]	Meta-analysis of randomized controlled trials	No difference in DVT rates between patients receiving LDH and no prophylaxis (OR 0.965, 95% CI 0.360, 2.965)	I
Rogers et al. (1993) [34]	Retrospective single center review	2525 patients reviewed with 25 total pulmonary embolic events. 92% of these were patients with severe head injuries, multiple long bone fractures, and pelvic fractures which are complex or involve the posterior elements with other long bone injuries, or patients with complete or incomplete spinal cord injuries, or patients who could not be anticoagulated	II

because the patient will require at least one operation for fixation of the acetabulum and femur fractures, the LMWH will need to be discontinued for a short period of time just prior to the planned surgery to allow for minimal bleeding risk during surgery. Additionally, this patient may have an IVC filter placed at the time of his orthopedic surgery as he has risk factors that put him at high risk for symptomatic pulmonary embolus [34]. LMWH is generally discontinued after the patient is able to mobilize on his own [37].

Predicting Outcomes

The patient can expect an overall VTE rate of between 1% and 6% [2, 6]. The rate of symptomatic PE, even in high-risk patients, is surprisingly low (at less than 1% incidence) [34]. As a result, we do not expect either of these complications with our management strategy. His outcome will primarily depend on the healing of his fractures and any potential sequelae from the articular injury associated with his acetabular fracture.

The patient can expect a relatively low rate of IVC-related complications. Rogers and coworkers studied 132 of their prophylactic IVC filters and found an insertional DVT rate of 3.1% [38]. The patency of IVC filters is 97% at 3 years [38]; however, the majority of IVC filters placed today are retrievable and can be removed when the patient is no longer at risk.

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31 The Infected Tibial Nail

Megan A. Brady, Seth A. Cooper, and Brendan M. Patterson

GL: Fifty-Four-Year-Old Male with Leg Pain

Case Presentation

GL, a 54-year-old male, presents to clinic with a 3-day history of foul-smelling discharge from his right leg. The patient's past medical history is significant for a Gustilo-Anderson type II open right midshaft tibial fracture. GL underwent irrigation and debridement, intramedullary nailing, and immediate closure of the wound 3 weeks prior to this admission. He denies any fever or chills but is complaining of increased pain in the right leg. GL's past medical history is negative. He takes no medications and has no allergies.

Vital signs are normal, and GL's current temperature is 99.1. Upon physical examination, there is purulent drainage from the incision site over the proximal interlocking screws. The right leg is erythematous and tender to palpation. The dorsalis pedis and posterior tibialis pulses are palpable and equal to the contralateral extremity. Sensation to light touch is intact in all dermatomal distributions. Right leg compartments are soft and compressible.

Laboratory values are:

WBC—16 cells/mm^3
CRP—128 mg/L
ESR—78 mm/h

Interpretation of Clinical Presentation

The symptoms and physical exam findings are consistent with an infected tibial shaft fracture, occurring in the acute postoperative period. GL suffered a type II open tibial shaft fracture 3 weeks prior. Radiographs (Fig. 31.1a–c) demonstrate a tibial shaft fracture with a large butterfly fragment, following insertion of an intramedullary tibial nail. The hardware is intact without radiographic evidence of loosening. There is no evidence of the fracture healing noted on any views. As is typical of an early postoperative infection, there are no radiographic signs of osteomyelitis, which would include bone resorption, periosteal bone formation, or cortical irregularity.

The tibia is the most frequent site for an open fracture, due to the subcutaneous nature of the

M. A. Brady
Iowa Methodist Medical Center, Des Moines Orthopedic Surgeons, West Des Moines, IA, USA

S. A. Cooper (✉)
Florida Medical Clinic, Department of Orthopaedic Surgery, Tampa, FL, USA

B. M. Patterson
Cleveland Clinic Main Campus, Case Western Reserve University School of Medicine, Department of Orthopedic Surgery, Cleveland, OH, USA

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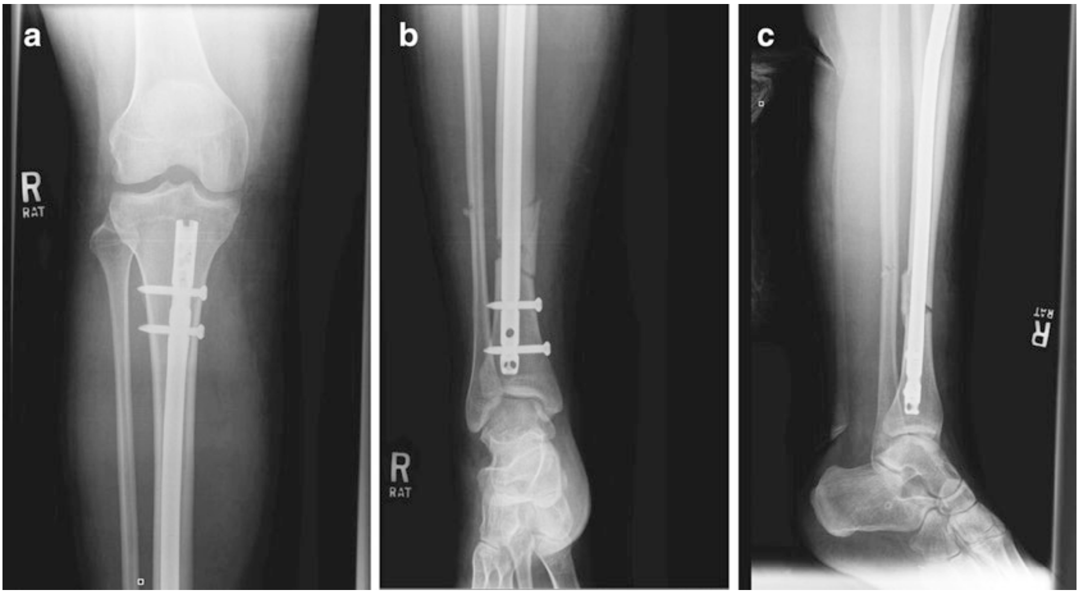

Fig. 31.1 (**a**, **b**) AP radiograph tibia. (**c**) Lateral radiograph tibia

anteromedial tibia [1]. Open tibial shaft fractures are frequently associated with severe bone and soft tissue injury, which increases the risk of infection and nonunion. Open fractures are described according to the Gustilo-Anderson classification system [2]. Type I injuries have minimal contamination and include open fractures associated with a wound less than 1 cm in length. This type is associated with minor soft tissue damage and low-energy fracture patterns. Type II injuries describe an open fracture associated with a wound greater than 1 cm but without extensive soft tissue damage. Type IIIA injuries include segmental open fractures or open fractures associated with extensive soft tissue damage. Type IIIA injuries have adequate soft tissue coverage that permit primary closure. Type IIIB injuries are associated with extensive soft tissue damage and bony stripping. These open, contaminated injuries often require soft tissue coverage. Type IIIC injuries require arterial repair for limb salvage [2, 3]. Type III open tibial fractures are problematic, with 27–77% complicated by deep wound infection.

The subcutaneous position of the tibia leads to increased soft tissue stripping and vascular disruption, making open tibial fractures more susceptible to infection [1]. Other factors increasing the infection risk following open tibial shaft fracture include diabetes mellitus, HIV status, and smoking. These factors also increase the risk of delayed fracture healing and nonunion. In 2008, Aderinto and Keating found a 52% rate of delayed union in diabetic patients with closed tibial shaft fractures, compared to nondiabetic patients [4]. Nine percent of the diabetic patients developed nonunions of the tibial shaft fracture, requiring exchange nailing to heal. All of the fractures in the nondiabetic patients healed without the need for additional surgery. The incidence of infection in the diabetic patients was 9%, compared to 0% infection rate in nondiabetic patients. Harrison and coworkers demonstrated infection rates from 71% to 100% in HIV-positive patients suffering open tibial fractures. These same patients also showed a trend toward nonunion compared to non-HIV patients with open tibial fractures [5]. Harvey and coworkers demonstrated decreased union rates in open tibial fractures treated with intramedullary nailing in smoking versus nonsmoking patients. Additionally, the time to union was significantly longer in patients who smoked. Smokers were also found to have an increased rate of complications, including infections [6]. The incidence of infection following open tibial shaft fracture varies according to the severity of soft tissue injury. The reported incidence of infection for type I open fractures ranges between 0% and 2%. The incidence of infection for type II open tibial fractures is 2–7% [2, 7]. The incidence of infection increases to 10–50% for type III open tibial fractures, which is due to the significant soft tissue injury and contamination [8]. Infection of an open tibial shaft fracture may lead to nonunion or even amputation. Therefore, the risk of infection must be minimized during the treatment of these fractures. While the fundamental concepts of open fracture management were discussed in Chap. 23, a brief review here is important.

Urgent antibiotics, thorough debridement, bony stabilization, and early soft tissue coverage are the mainstays in the treatment of open tibial fractures.

Antibiotics should be given as soon as possible after injury [9]. A first-generation cephalosporin for gram-positive coverage should be given to all patients with open fractures. Patzakis and coworkers demonstrated a significant decrease in infection rates with first-generation cephalosporin administration for open fractures. In this study, 310 patients were randomized to three treatment groups. The first group received a first-generation cephalosporin, the second group received no antibiotics upon presentation, and the final group received a combination penicillin and streptomycin. The patients treated with a first-generation cephalosporin had a significantly decreased infection rate (2.3%), compared to patients treated with no antibiotics (13.9%) or a combination of penicillin and streptomycin (9.8%) [7]. Coagulase-positive *Staphylococcus aureus* and β-hemolytic streptococci were the most commonly found organisms. The efficacy of first-generation cephalosporins in the initial management of open fractures has been repeatedly shown in subsequent studies. Type III fractures are at higher risk for gram-negative contamination; therefore, an aminoglycoside should also be given in these instances [2]. Antibiotics are continued for 24–48 h following definitive wound closure [1]. Dellinger and coworkers investigated the effect of the duration of prophylactic antibiotics in open fractures. Two hundred forty-eight patients were randomized to two treatment groups, 1-day versus 5-day course of intravenous cephalosporin. The rate of infection with 1-day duration of antibiotic prophylaxis was 12.7%, compared to 11.8% with a 5-day duration. This study demonstrated that shorter courses of antibiotics are as effective as prolonged courses [10].

Bony stabilization options include external fixation, intramedullary nail, or plate-and-screw fixation. In 2007, Kakar and Tornetta demonstrated a 3% rate of infection following immediate unreamed intramedullary nailing of open tibial shaft fractures [11]. One hundred forty-three type IIIB open tibial fractures underwent immediate intramedullary nailing following thorough irrigation and debridement. Of the 143 open tibial fractures, one patient developed superficial infection. Only four of the 143 fractures developed a deep infection. This study demonstrated that urgent surgical irrigation and debridement, followed by immediate tibial nail insertion, is a safe and viable option to manage open tibial shaft fractures. Intramedullary nailing also allows maintenance of length and alignment, as well as early weight bearing and range of motion of adjacent joints.

This patient received appropriate initial care for his open tibial shaft fracture. He underwent surgical irrigation and debridement, followed by intramedullary nailing. The wound was primarily closed at the time of the initial surgery. The patient now presents with a 3-day history of foul-smelling drainage, erythema, and drainage from the right leg, symptoms concerning of infection. Additionally, the patient has elevated inflammatory markers.

Declaration of Specific Diagnosis

The patient, GL, presents with an infected tibial shaft fracture 3 weeks after undergoing excisional debridement and tibial intramedullary nailing.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals are:

1. Clearance of postoperative infection
2. Achieving fracture union
3. Avoidance of chronic infection
4. Early mobility of ankle and knee

Treatment options include:

1. Hardware retention and surgical debridement
2. Hardware removal, surgical debridement, and stabilization with external fixation
3. Hardware removal, surgical debridement, and stabilization with temporary antibiotic nail and then revision intramedullary nail placement
4. Hardware removal, surgical debridement, and stabilization with revision intramedullary nail placement
5. Hardware removal, surgical debridement, and cast/splint immobilization

Evaluation of the Literature

An extensive literature search was performed on infected nonunion of the tibia using Medline and PubMed. Keywords utilized during the search included "tibia fracture", "diaphyseal", "infection", "nonunion", and "treatment". This search found 62 abstracts, all of which were reviewed. From this search, 12 articles and their references were reviewed. The search was limited from 1970 to 2011. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

Hardware Removal Versus Retention, Surgical Debridement, and Fracture Stabilization

Infection in the presence of a non-healed fracture is a challenging situation, as management requires both treatment of the fracture and eradication of the infection. The fracture must be stabilized in some manner, either operatively or non-operatively. In addition, the infection must be treated and cleared in order to achieve successful bony union. Traditionally, the treatment has consisted of surgical debridement with hardware removal, local and systemic antibiotics, and provisional stabilization of the fracture. A second procedure for definitive stabilization was performed following clearance of the infection [12].

An alternative strategy consists of surgical debridement, antibiotic therapy, and retention of hardware. The argument for hardware retention is the maintenance of fracture stability. Whether or not the hardware is to be retained, urgent and thorough debridement is paramount. All necrotic or grossly contaminated tissue should be excised, as well as any avascular bone. Preoperative antibiotics should be held until multiple sets of intraoperative cultures have been obtained. Following this, broad-spectrum antibiotics are given until culture results have returned. Culture-specific antibiotic therapy is then initiated. Local antibiotics can be administered with antibiotic-impregnated beads. The beads allow for a high concentration of antibiotics at the site of infection while minimizing the adverse effects of systemic antibiotic therapy [12]. Calhoun and coworkers compared the efficacy of local antibiotic beads and long-term intravenous antibiotic therapy in the treatment of infected nonunion. Fifty-two patients with septic nonunions were randomized into two treatment arms. The first group included 24 patients treated with surgical debridement and 4 weeks of intravenous antibiotics. The second group consisted of 28 patients, who were treated with debridement, gentamicin-polymethylmethacrylate beads, and perioperative broad-spectrum intravenous antibiotics. The healing rate of the infected nonunions was similar in both groups: 83.3% in intravenous antibiotic group and 85.7% in the local antibiotic bead group [13]. In addition, antibiotic beads or pouches act to fill dead space created by bony or soft tissue defects.

In 1987, Merritt and Dowd demonstrated that stabilization of open fractures resulted in a statistically significant decreased rate of infection with gram-positive organisms [14]. This study examined the incidence of infection in open femur fractures in an animal model. Femoral osteotomies were created in hamster femora. Half of the osteotomies were allowed to heal without intervention, while others underwent internal fixation using a 0.9-mm K-wire. The infection rates were compared between the stabilized and non-stabilized fractures. The fixed group was found to have lower infection rates compared to unfixed fractures. This study demonstrated that internal fixation reduces infection rate with gram-positive organisms. This finding is relevant, as the most common organism found in infected fractures is *S. aureus*. However, these infections are often polymicrobial [12]. It is necessary to maintain some form of fracture stabilization until bony union, but hardware retention versus removal is debatable. This is especially true in the tibia where there are many options, including internal fixation and even splinting.

In 2010, Berkes and colleagues performed a retrospective analysis to determine the success rate of treating early postoperative infections with surgical irrigation and debridement, antibiotic therapy, and hardware retention [15]. The authors evaluated 87 fractures that developed a postoperative infection less than 6 weeks after surgical fixation. The overall success rate was 71%, defined as fracture union with retention of hardware. Open fracture and the presence of intramedullary nail were found to be predictors of treatment failure. Of the 36 failures (29%), seven patients went on to require amputation. Additionally, union rates with debridement differed between plates versus nails. The union rate for plate fixation was 80%, compared to a union rate of 50% associated with intramedullary nailing. This study also demonstrated that infections with *pseudomonas* and smoking were predictive factors regarding likelihood of nonunion. The authors concluded that deep infection following fracture fixation could be successful when treated with surgical debridement, antibiotic therapy, and hardware retention until fracture union, but the surgeon needs to consider patient factors, injury factors, implant, and bacteria type in making a decision on retention versus removal.

Conversely, others feel that the retention of hardware leads to difficulty eradicating infection. Metal implants can promote adherence of microbes and biofilm formation, which have adverse consequences on phagocytosis [16]. Gristina and Costerton demonstrated biofilm formation on metal surfaces in implant-related infection using electron microscopy of surgically removed hardware. This study found causative microorganisms in glycocalyx-encased biofilms, which were found to be adherent to surfaces of biomaterial and tissues in 76% of implant-related infections [17]. Biofilm formation is an essential feature for implant-related infections, as the glycocalyx allows bacteria to evade host defense mechanisms. The biofilm also allows bacteria to be more resistant to antibiotic therapy, thus explaining why implant-related infections have a poor response to antibiotic treatment [17]. The ability of bacteria to form a biofilm is a virulence factor. Implant-related infections may not be cured until the hardware is removed.

Some experts advocate hardware removal as necessary to eliminate the biofilm, as well as to provide adequate access for an aggressive debridement of all devitalized soft tissue and bone [17]. Additionally, removal of the intramedullary nail allows for debridement of the canal. Biofilm removal and aggressive debridement allows for higher chance of successful treatment of infection.

However, hardware removal necessitates an alternative form of fracture stabilization. Options include external fixator, antibiotic-impregnated cement spacing nail, immediate revision intramedullary nailing at time of debridement, or cast/splint immobilization. Fracture stabilization is necessary, as it prevents gross motion at the fracture site. Fracture stabilization has been shown to decrease the incidence of infection, as previously described in the Merritt and Dowd study [14]. Fracture stabilization also decreases pain in an animal model.

Hardware Removal, Surgical Debridement, and External Fixation

External fixation is well tolerated in the tibia and is simple to apply following a thorough debridement. Disadvantages of external fixation include pin tract infection, low patient tolerance, and fracture through pin sites.

Circular external fixators are another option for treating infected tibial nonunions, using either the Taylor spatial frame (TSF, Smith & Nephew, Memphis, TN) or an Ilizarov frame. Rozbruch and colleagues performed a retrospective review of 38 tibial nonunions treated with the TSF. Nineteen patients (50%) of the tibial nonunions were infected, which were treated with 6 weeks of culture-specific antibiotics. Twenty-three patients had large bony defects (average 5.9 cm), while 22 patients had a leg-length discrepancy (average 3.1 cm). Twenty-seven (71%) of the 38 fractures went on to bony union after initial frame placement; however, infection was a factor associated with both initial treatment failure and persistent nonunion. Of the eleven persistent nonunions, nine were infected. Four persistent nonunions were treated with reapplication of TSF. Three patients underwent intramedullary nailing, while two went on to receive plate and screw fixation of the nonunion. Two patients with persistent nonunion and infection went on to require amputation. Overall, 36/38 (95%) patients went on to achieve bony union. The average leg-length discrepancy improved to 1.8 cm. Rotational alignment also improved. Thirty-two of the 36 patients were found to have an alignment deformity <5°, while four patients had alignment within 6–10° of the contralateral side. TSF placement is an alternative method to provide bony stability while treating infected nonunions of the tibia. An additional benefit of circular fixators involves the ability to address bony defects and rotational abnormalities. This treatment regimen is useful in tibial nonunions associated with infection, bone loss, rotational abnormalities, leg-length discrepancy, or a traumatized soft tissue envelope. Nonunions associated with large bony defects are more safely treated with a ringed external fixator, as the correction is gradual [18]. Plate and intramedullary fixation requires acute fixation, which is not always possible in the face of large bony defects. Internal fixation is also less than ideal in the setting of a poor soft tissue envelope. The surgical goals of treating infected nonunions of the tibia include a thorough debridement and removing all dead bone. The circular fixators allow for bone transport or acute shortening with gradual lengthening in order to address a defect created by debridement. Bone transport is performed following resection of large amounts of dead bone through a corticotomy and gradual distraction osteogenesis [19]. The frame is also advantageous in patients with previous flaps, as large incisions are not required for fixation.

One of the potential disadvantages of circular external fixation is the long duration of treatment, which may be associated with patient discomfort and pin tract infection [20, 21]. Thies and colleagues performed an audit of 33 adult patients treated with circular external fixation for lower limb deformities. There were 38 cases of pin site infections, which all responded to oral antibiotics. None of the pin site infections resulted in osteomyelitis [21].

Hardware Removal, Surgical Debridement, Temporary Antibiotic Nail, and Revision Intramedullary Nail Placement

Paley and Herzenberg described using an antibiotic cement rod to treat infections following intramedullary nailing, which provides some fracture stability while allowing for hardware removal [22]. The surgical protocol involves removal of the intramedullary rod, followed by excision of draining sinus tract (if present). The medullary canal is reamed 1–2 mm greater than the nail diameter for further debridement, followed by insertion of the antibiotic-laden cement rod. In this study, Paley and Herzenberg not only describe the technique but also provide a retrospective analysis of nine patients with intramedullary infections treated with this method. Nine patients with intramedullary infections following intramedullary nailing procedures underwent hardware removal, debridement, and antibiotic cement rod placement. Four of the patients had fracture nonunions, secondary to infection. Three patients were being treated for unhealed osteotomy sites due to lengthening procedures. All patients had documented intramedullary infection. All cases of nonunion were protected with removable braces to supplement the cement rod fixation. There were no cases of recurrent infection during a 38–48 month follow-up period. None of the nine patients required antibiotics following nail removal [22]. Use of an antibiotic-impregnated cement spacer is an inexpensive method to treat intramedullary infections, as it provides local antibiotic therapy and bony stability.

Court-Brown and colleagues described a protocol for the treatment of postoperative infection of the tibia following intramedullary nailing [23]. Four hundred fifty-nine fractures were treated with intramedullary nailing. Thirteen patients developed a postoperative infection. The incidence of infection for closed or type I open fractures was 4.1%. The incidence of infection associated with type II open fractures was 3.8%, compared to 9.5% after type III open fractures. Twelve cases were successfully treated without recurrence of infection. The nail was retained in patients with closed or type I open tibial fractures; however, patients with persistent drainage underwent exchange nailing with reaming of the intramedullary canal. Patients with type II and type III open fractures were treated with nail removal. Necrotic bone and skin were also resected at this time. Revision intramedullary nailing was then performed in these cases. All patients received intravenous antibiotics [23].

Thonse and Conway described a single-stage procedure for the treatment of infected tibial nonunions using antibiotic cement-coated interlocking intramedullary nails [12]. Following thorough surgical debridement and hardware removal, an antibiotic cement-coated interlocking nail was prepared in the operating room using a commercially available intramedullary nail. The technique for nail preparation is described in detail in the article. Thonse and Conway retrospectively evaluated 20 patients who underwent this technique. Seventeen patients (85%) went on to fracture union. The infection was cleared in the three remaining fractures, all of which had a stable nonunion. Nineteen (95%) of the 20 patients cleared the infection. One patient, although achieving fracture union, continued to experience wound drainage. This patient required eventual above-the-knee amputation. Three (15%) patients required exchange nailing to a second antibiotic cement-coated interlocking nail due to continued infection. Four (20%) patients were noted to have cement debonding (separation of cement mantle from underlying nail) during removal of the cement-coated nail. The use of the antibiotic cement-coated interlocking nail is another method, which allows for a single surgical procedure to deliver local antibiotics and provide fracture stability.

New intramedullary implants have emerged in which the nail comes pre-coated with gentamicin. The ETN Protect™ (Depuy Synthes, West Chester, PA, USA) intramedullary nail is a titanium alloy that has a fully absorbable antibiotic coating. Within 48 h after implantation, 80% of the antibiotic has resorbed. In their study, Metsemakers and colleagues evaluated 16 tibial fractures treated with this implant [24]. At the conclusion of their study, they found no deep infections and four nonunions, one of which was a revision case. This implant, and others like it, offers not only stability to the fracture site but also an antibiotic delivery system [24].

Evidentiary Table and Selection of Treatment Method

The relevant studies regarding treatment options for an infected tibial shaft fracture following intramedullary nail placement are summarized in Table 31.1 [12, 15, 19, 20, 22, 24]. Based on the literature review, a two-staged procedure is the best treatment option for the case presented.

Table 31.1 Evidentiary table: A summary of the existing evidence for treating infected tibial nonunion following intramedullary nailing

Author (year)	Description	Summary of results	Level of evidence
Metsemakers et al. (2015) [24]	Retrospective case series	16 patients with 16 tibia fractures (Gustilo type II–IIIB) treated with commercial antibiotic-coated nail. No deep infections found at final follow-up (minimum follow-up was 18 months). Four nonunions, one of which was a revision	III
Berkes et al. (2010) [15]	Retrospective case series	123 postoperative wound infections developing within 6 weeks of fracture fixation, which were treated with surgical debridement, hardware retention, and antibiotics. Success rate of 71%, defined as fracture union. Open fracture and the presence of intramedullary nail were found to be predictors of treatment failure	III
Paley and Herzenberg (2002) [22]	Retrospective case series	9 intramedullary infections treated with antibiotic-impregnated cement rods, no recurrent infection occurred during 38–48-month follow-up period. No patients required antibiotics following nail removal. One case of fracture following cement rod removal, in which the rod had remained for >1 year	III
Thonse et al. (2007) [12]	Retrospective case series	20 patients with infected nonunions of the tibia or femur treated with a single-stage procedure, using an antibiotic cement-coated interlocking nail. Bony union was achieved in 85%. Infection was cleared in 95%. 15% required exchange nailing with another cement-coated nail in order to clear infection	III
Rozbruch et al. (2008) [20]	Prospective case series	38 tibial nonunions treated with Taylor spatial frame. 71% rate of bony union. Presence of infected nonunion found to correlate with initial frame failure and persistent nonunion. 28/36 patients found to have significant improvement in alignment of deformity. Leg-length discrepancy also improved from 3.1 to 1.8 cm	II
Struijs et al. (2007) [19]	Meta-analysis	Literature review performed of 16 case series evaluating single-stage surgical protocol and 18 case series of two-stage surgical protocol. Union rates associated with single-stage treatment: 66–100%, compared to 75–100% for two-stage procedures (debridement, local antibiotics, planned secondary fixation). The rate of persistent infection for single-stage procedures ranged between 0 and 55%, compared to 0–18% for two-staged protocol	II

The first surgical stage would consist of hardware removal, surgical debridement, and placement of a cement spacing nail. This would be followed by repeat intramedullary nailing once the infection has cleared.

Hardware retention in the acute postoperative period has been shown to be successful in some patients. However, based on the study performed by Berkes and colleagues, a history of open fracture and the presence of intramedullary nail were both associated with treatment failure. GL had a type II open tibial shaft fracture and underwent intramedullary nailing following surgical debridement. Hardware removal provides the more reliable means of clearing the infection, as it allows for a more aggressive surgical debridement. Additionally, hardware removal also facilitates placement of intramedullary antibiotic cement.

Treatment with a circular external fixator is also an option. GL does not have evidence of malalignment or bone loss. It is highly unlikely that extensive bony resection would be required during the surgical debridement. Additionally, there are no concerns regarding the soft tissue envelope, as the wound underwent primary closure at the time of surgical debridement.

A single-stage surgical approach is another option; however, this is associated with lower union rates compared to the two-stage approach. Struijs and colleagues performed a meta-analysis evaluating treatment outcomes of infected nonunion of the long bones [19]. The data from 1388 patients were included in this study. The outcomes following single-stage treatment protocol had union rates between 70% and 100%, compared to union rates of 93–100% for two-staged procedures using surgical debridement, local antibiotics, and a planned secondary fixation procedure. Rates of persistent infection with single-staged treatment ranged between 0% and 60%, which was higher than seen with the two-staged approach (0–18%). Based on these data, a two-staged surgical procedure offers the most reliable outcome.

Definitive Treatment Plan

Treatment goals in GL's case include eradication of infection and achieving fracture union, which require thorough debridement, antibiotic therapy, and bony stability. Fortunately, the infected nonunion is not associated with a compromised soft tissue envelope, limb malalignment, or a large bony defect.

The initial surgical procedure entails removal of the intramedullary nail, followed by thorough surgical debridement and irrigation. All dead bone and nonviable tissue are resected at this time. Antibiotic irrigation of the canal, using proximal to distal drainage through the supramalleolar interlocking sites, is performed to ensure adequate debridement of the intramedullary canal. An antibiotic-cement spacing nail fashioned according to the technique described by Paley and Herzenberg would then be placed [22]. The antibiotic-impregnated cement spacing nail serves to provide both local antibiotic therapy and offer bony stability. Postoperatively, the limb is placed in a splint. The patient is treated within 6 weeks of culture-specific intravenous antibiotics. Upon completion of antibiotics, the patient is clinically evaluated to ensure that the infection has been eradicated. This is done with a combination of physical examination and laboratory tests, including erythrocyte sedimentation rate and C-reactive protein tests [25]. Once the patient shows no evidence of infection, it is appropriate to proceed with the second surgical stage. At this point, the cement spacer nail is removed, and an intramedullary nail is placed. All wounds are primarily closed at this time. Postoperatively, the patient is placed in a splint to allow for soft tissue rest. Upon return to clinic, weight-bearing status is advanced.

Predicting Outcomes

The long-term results of patients treated with a two-stage surgical procedure are favorable. Literature review shows the union rates between 75% and 100% using a two-stage strategy, with the incidence of persistent infection ranging between 0% and 18% [19]. In the retrospective analysis performed by Paley and Herzenberg, there was no recurrence of infection at time of final follow-up. The two-stage procedure utilizing an antibiotic-impregnated cement spacing device, antibiotic therapy, and secondary fixation provides superior outcomes compared to hardware retention or single-staged procedures. This approach also negates the need for long-term treatment in an external fixator, minimizing patient discomfort and associated external fixator complications.

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32 Perioperative Optimization in Orthopedic Trauma

Jesse M. Ehrenfeld and Michael C. Lubrano

KN: 81-Year-Old Female with Hip Pain

Case Presentation

KN is an 81-year-old female who presents to the emergency department with a chief complaint of left hip pain after falling down during a syncopal episode. The patient is an independent ambulatory, community dweller who denies any other injuries or pain. On primary survey, she demonstrates a GCS of 15 and a patent airway and is hemodynamically stable. On secondary survey, no gross deformities of her left lower extremity are noted.

Past medical history is significant for atrial fibrillation, congestive heart failure (CHF), emphysema, and non-insulin-dependent diabetes mellitus.

Current medications include warfarin, furosemide, metformin, and an albuterol inhaler.

J. M. Ehrenfeld (✉)
Department of Anesthesiology, Surgery, Biomedical Informatics and Health Policy, Vanderbilt University School of Medicine, Vanderbilt University Medical Center, Nashville, TN, USA
e-mail: Jesse.ehrenfeld@vanderbilt.edu

M. C. Lubrano
Department of Anesthesia and Perioperative Care, UCSF School of Medicine, San Francisco, CA, USA

Physical examination reveals the patient to be awake, alert, and in no acute distress. The left foot appears externally rotated compared to the right. The dorsalis pedis and posterior tibialis pulses are palpable; sensation to light touch is intact in all dermatomal distributions. All compartments are soft.

Radiographs of the pelvis and left hip are demonstrated in Fig. 32.1a, b.

Interpretation of Clinical Presentation

The patient's findings are consistent with a low energy mechanism producing an isolated left femoral neck fracture. The patient has significant comorbid conditions including advanced age, atrial fibrillation, CHF, chronic obstructive pulmonary disease (COPD), and diabetes mellitus. Based on this history, cardiac, pulmonary, endocrine, and cognitive function should be the initial focus of the preoperative evaluation. A comprehensive medical history and physical examination is the mainstay for perioperative risk assessment. This evaluation directs medical tests that confirm diagnoses, analyzes disease processes, facilitates perioperative management, and optimizes the patient.

Hip fractures have a profound impact on the morbidity and mortality of the elderly due to their common association with death from

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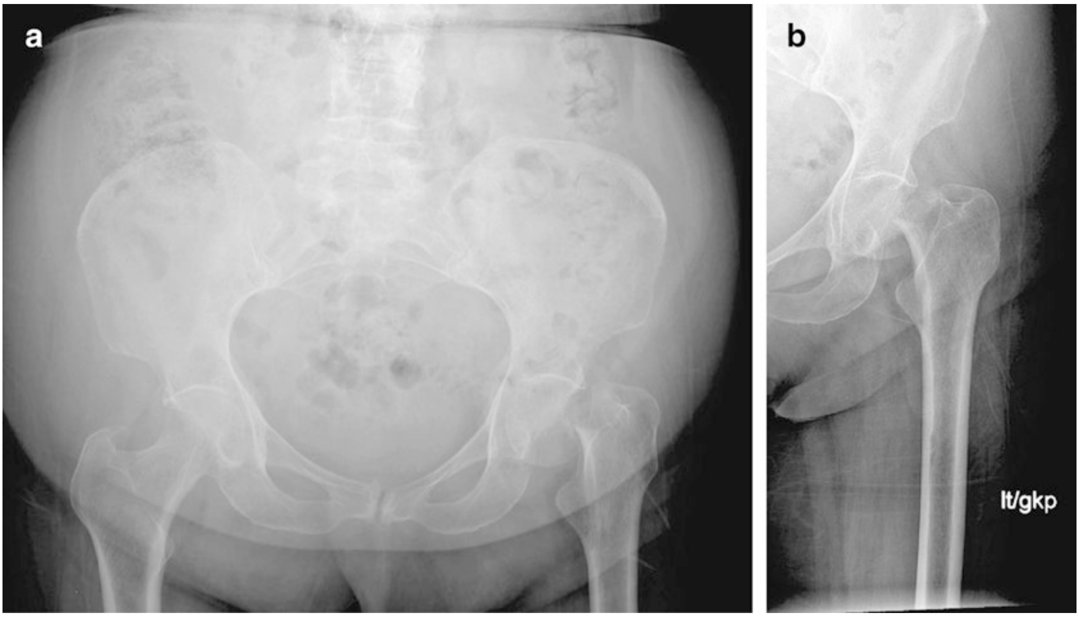

Fig. 32.1 (**a**) Pelvic radiograph (**b**) Left hip radiograph

myocardial infarction, CHF, pneumonia, and pulmonary embolism [1–3]. In addition, hip fracture patients have an increased mortality risk which persists over time compared to aged-matched controls who have not had a fracture [4]. Delaying surgery for hip fracture patients beyond 48 h has been shown to increase mortality [5–7]. One meta-analysis, which included 5 prospective and 11 observational studies and evaluated over 250,00 patients, revealed that the operative delay beyond 48 h increased the 30-day mortality rate by 41% and the 1-year mortality rate by 32% [7]. Other studies have shown that preoperative optimization decreases postoperative complications [8, 9]. In a prospective study with 571 patients with hip fractures, patients who were taken to surgery with major clinical abnormalities (e.g., uncontrolled atrial fibrillation, CHF, COPD, recent myocardial infarction) had a high rate of significant postoperative complications [9]. The presence of more than one major abnormality before surgery [odds ratio (OR): 9.7, 95% confidence interval (CI): 2.8–33.0] or the presence of major abnormalities on admission that were not corrected prior to surgery (OR 2.8, 95% CI 1.2–6.4) was independently associated with the development of postoperative complications. While warranting correction, minor abnormalities (e.g., moderate hypertension, mild electrolyte disturbances, moderate anemia) were not associated with increased risk of complications (OR 0.70, 95% CI 0.28–1.73). In summary, hip fracture surgery should be performed as soon as major preoperative medical abnormalities have been corrected, preferably within 48 h.

Cardiovascular disease is a major risk factor for poor outcomes in the perioperative period for the elderly. KN has atrial fibrillation and CHF. An ECG and chest radiograph should be obtained. The ECG will characterize the atrial fibrillation rate control, which should be less than 100 beats per minute. It may also elicit evidence of underlying coronary artery disease. The chest radiograph along with the physical examination will help delineate compensated from uncompensated CHF. The American College of Cardiology/American Heart Association (ACC/AHA) guideline on perioperative cardiovascular evaluation for noncardiac surgery is a succinct, simple algorithm for evaluating the cardiac fitness for surgery (Fig. 32.2) [10, 11]. During the

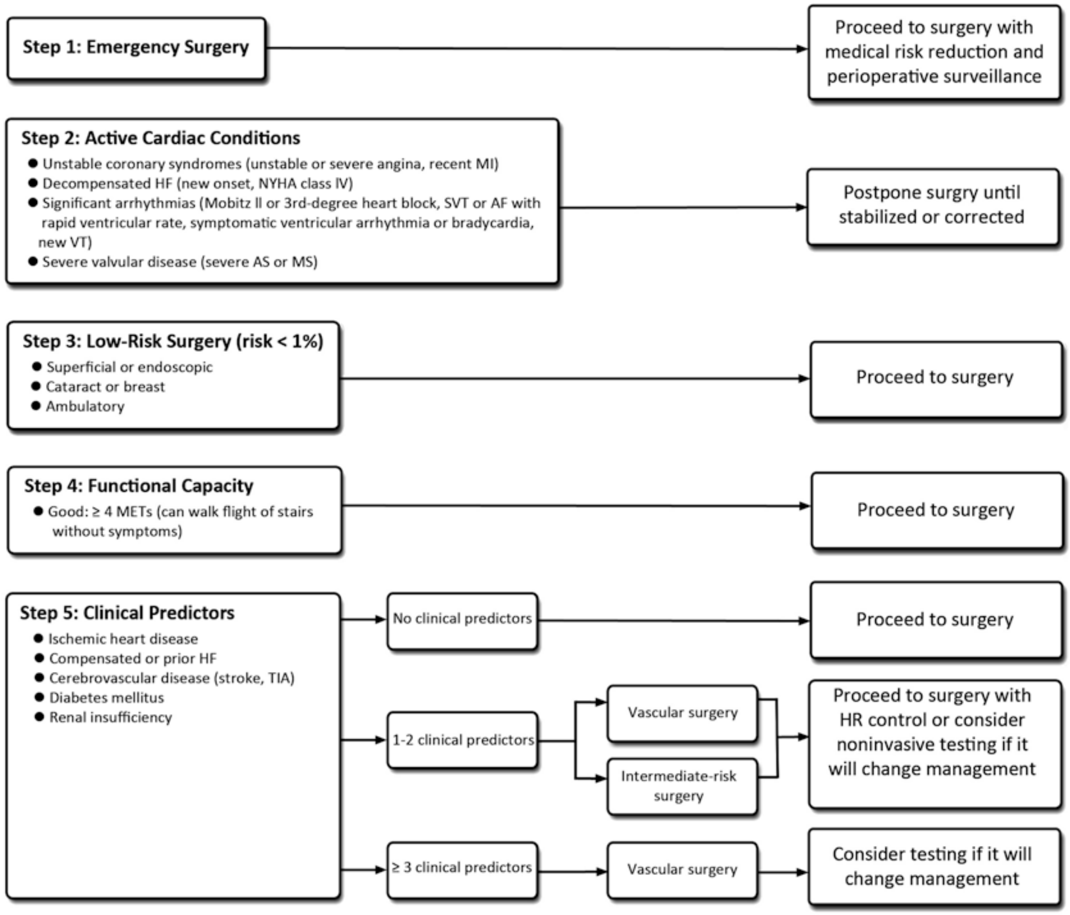

Fig. 32.2 Simplified cardiac evaluation algorithm for noncardiac surgery. AF atrial fibrillation, AS aortic stenosis, HF heart failure, HR heart rate, METs metabolic equivalents of the task, MI myocardial infarction, MS mitral stenosis, NYHA New York Heart Association, SVT supraventricular tachycardia, TIA transient ischemic attack, VT ventricular tachycardia (Data from Refs. [10, 11]; Figure adapted with permission of Elsevier from Miller and Eriksson [41])

cardiac evaluation if auscultation reveals an undiagnosed systolic murmur, aortic stenosis should be considered. Aortic stenosis has an increasing prevalence with age, and morbidity and mortality remain high for patients undergoing surgery with severe aortic stenosis [12, 13]. In the elderly, only asymptomatic grade 1 or 2 mid-systolic murmurs without ECG and chest radiograph evidence of cardiac disease do not require any further workup [14]. Otherwise, all new or previously unrecognized murmurs should be evaluated by an echocardiogram prior to surgery.

A recent study evaluated the utilization of perioperative TTE for hip fracture patients [15]. There were 100 geriatric patients included in the study, all of whom had received TTE evaluations prior to their surgeries. Only 66% of these patients received TTEs in accordance with the published recommendations from the ACC/AHA. Researchers then evaluated TTE findings for disease process that triggered an alteration in anesthetic plan (valvular disease, ventricular dysfunction, pulmonary hypertension, etc.). Only 14% of patients had TTEs revealing findings that warranted a change in anesthetic management; all of these patients met criteria for TTE based on the ACC/AHA recommendations. These findings were consistent with ACC/AHA

Table 32.1 American Society of Anesthesiologists Physical Status Classification

ASA 1	Healthy patient without organic, biochemical, or psychiatric disease
ASA 2	Mild systemic disease, e.g., mild asthma or well-controlled hypertension
ASA 3	Moderate-to-severe systemic disease that limits normal activity, e.g., renal failure on dialysis
ASA 4	Severe systemic disease that is a constant threat to life, e.g., acute myocardial infarction
ASA 5	Moribund patient who is not expected to survive for 24 h with or without surgery
ASA 6	Brain-dead organ donor

"E" added to the classification to denote emergency surgery

guidelines being 100% sensitive and 40% specific for finding abnormalities that alter anesthetic plan.

Postoperative pulmonary complications are just as prevalent as cardiac complications and contribute similarly to poor outcomes [16, 17]. In a systematic review of more than 100 studies and over 150,000 patients, risk factors that were predictive of postoperative pulmonary complications that are applicable to hip fracture surgery included advanced age, American Society of Anesthesiologists (ASA) Physical Status Class 2 or higher (Table 32.1), functional dependence, COPD, CHF, emergency surgery, general anesthesia, prolonged surgery, and serum albumin level less than 30 g/L [17]. Insufficient evidence supported preoperative pulmonary function tests (spirometry) as a tool for risk stratification. Obesity and well-controlled asthma were not risk factors. KN has three risk factors for postoperative pulmonary dysfunction: advanced age, COPD, and CHF. Pulmonary examination of hip fracture patients should include auscultation of all lung fields, determination of oxygen saturation by pulse oximetry, and if indicated, a preoperative chest radiograph.

Diabetes mellitus is an independent risk factor for postoperative cardiac complications. In addition, diabetes places patients at increased risk of mortality, heart failure, renal failure, and infections. A retrospective analysis of 2030 patients revealed an in-hospital mortality rate of 16% in newly diagnosed diabetic patients compared to 3% in patients with a prior history of diabetes [18]. The American College of Endocrinologists Position Statement recommends a target glucose level of ≤110 mg/dL in critically ill patients and fasted noncritically ill hospitalized patients [19]. No consensus target range currently exists for intraoperative glucose values; however, most anesthesiologists aim to maintain glucose levels ≤180–200 mg/dL based on available evidence. A preoperative ECG along with electrolytes, BUN, creatinine, and blood glucose is recommended for all diabetic patients.

Cognitive function and preinjury functional status are also significant factors in hip fracture patient outcomes [20, 21]. In a prospective cohort study with 1944 patients, mental status examination was correlated with an increased mortality rate over a 24-month period [21]. Depending upon the underlying cause, no intervention may be possible for cognitive dysfunction before surgery. However, poor cognitive function may be associated with malnutrition, dehydration, infection, diabetes, and electrolyte imbalances. Furthermore, an intracranial event may have caused or resulted from a hip fracture due to a fall. Therefore, a search should always be conducted for correctable causes of cognitive dysfunction prior to surgery.

Other organ systems that should be considered for evaluation include the renal, hepatic, and hematologic systems. Renal function is essential for water homeostasis, electrolyte homeostasis, and drug/toxin elimination. Renal failure may be an underlying medical condition or occur as a result of general anesthesia and surgery. Renal function is frequently evaluated with serum BUN and creatinine. Liver disease affects protein metabolism (including synthesis of coagulation factors and albumin), drug metabolism, and bile regulation. The liver is assessed by obtaining liver function tests, coagulation studies (anticoagulants may alter), and/or albumin. Severe anemia is a major clinical abnormality leading to poor outcomes after hip fracture surgery [9]. A hemoglobin or hematocrit should be obtained and anemia corrected if indicated. The practice guidelines for transfusion by the ASA recommend transfusion of red blood cells when the hemoglobin is less than 6 g/dL in young, healthy patients [22]. A transfusion is typically not needed for a hemoglobin level greater than 10 g/dL. In the range between 6 and 10 g/dL, the determination to transfuse is based upon ongoing blood loss (factoring in rate and magnitude), intravascular volume status, and risk factors (e.g., low cardiopulmonary reserve, high oxygen consumption) for complications due to inadequate oxygenation.

Declaration of Specific Diagnosis

KN is an 81-year-old female with atrial fibrillation, CHF, COPD, and diabetes mellitus who presents with a displaced left femoral neck fracture.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals for anesthesia consist of the following objectives:

1. Preoperative medical optimization
2. Intraoperative anesthesia, analgesia, and hemodynamic stability
3. Postoperative hemodynamic stability and pain control

Treatment options for anesthesia include:

1. General anesthesia
2. Regional anesthesia:
   (a) Neuraxial: spinal or epidural
   (b) Peripheral nerve blockade

Evaluation of the Literature

Medline and PubMed searches were performed for relevant publications regarding preoperative evaluation of hip fracture patients and anesthesia for hip fracture patients. Keywords included the following: “hip fracture”, “preoperative evaluation”, “regional anesthesia”, and “general anesthesia”. MeSH headings included “hip fracture”, “anesthesia conduction”, and “nerve block”. The search was limited to human studies from 1975 to 2011 and identified 397 abstracts that were reviewed. The resulting publication list was then hand searched, emphasizing randomized controlled trials, reviews, and meta-analyses. One hundred twenty-five articles were read and reference lists reviewed. For the second edition of this textbook, a similar search was conducted for articles in English published between 2011 and 2017.

Detailed Review of Pertinent Articles

The following sections present an overview of general anesthesia and regional anesthesia and then review the literature that is relevant for the care of hip fracture patients.

Preoperative Medical Evaluation and Optimization

A thorough evaluation of a patient prior to the date of surgery is paramount in order to assure a reduction in mortality. This evaluation should be conducted in a typical history and physical fashion for all geriatric patients undergoing surgery.

A list of peer-reviewed and recommended items to consider in every geriatric patient perioperatively has been adapted and included in Table 32.2 [23]. These items have been validated

Table 32.2 Preoperative assessment of the geriatric surgical patient

Cognitive ability and capacity
Depression screening
Post-op delirium screening
Substance abuse/dependence screening
Cardiac evaluation according to the ACC/AHA algorithm
Screening for postoperative pulmonary complication risk
Functional status and fall history
Baseline frailty score
Nutrition status assessment
Evaluate for polypharmacy
Elderly patient-appropriate diagnostic tests

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and published by the American College of Surgeons National Surgical Quality Improvement Program (NSQIP). Cognitive screening is recommended, and for this the mini cognitive assessment is a recommended tool. Screening for depression using the PHQ-2 has not been validated in frail elderly patients; however, given the prevalence of depression in this population, efforts should be made to assess this. Depression alone has been shown to increase mortality and length of hospital stay after coronary artery bypass grafting. Furthermore, the CAGE (cut down, annoyed, guilty, eye opener) questionnaire is a well-established method of assessing for alcohol abuse.

The cardiovascular evaluation is incredibly important to the safety of elderly patients undergoing hip procedures in particular. Overall, the ACC/AHA guidelines recommend transthoracic echocardiograms (TTE) in patients with (1) dyspnea of unknown origin, (2) worsening of known signs or symptoms of heart failure, (3) known history of valvular dysfunction or heart failure without TTE in the last year or with worsening symptoms, and (4) suspicion of moderate or greater valvular stenosis or regurgitation. Any of these patients should be ordered for a preoperative TTE. As previously discussed, a recent study has shown these recommendations to be 100% sensitive for discerning lesions concerning for altering the anesthetic plan. Adhering strictly to these guidelines may also reduce unnecessary TTEs by one third [15]. Postoperative troponin assessment was helpful in stratifying 1-year mortality risk; however, in one study where these patients were randomized to standard care and intense, cardiology care, the intensive care did not improve mortality risk. Thus unless there is a clinical indication, routine troponin evaluation postoperatively is not a standard of care [24].

Pulmonary complications are common in postoperative patients and contribute to morbidity and mortality. Risk factors in elderly patient include COPD, CHF, OSA, pulmonary hypertension, elevated serum creatinine, and current cigarette use among others. Procedures that last beyond 3 h, general anesthesia, and residual neuromuscular blockade post-op are additional examples of factors related to the procedure that may contribute to this and should therefore be avoided, if possible. It is also important to note that diabetes, controlled asthma, and obesity are not considered factors that may contribute here.

Medication management is an additional, serious concern for elderly patients. It is recommended that all medications be reviewed, especially those that are over the counter, vitamins, herbal products, or nonsteroidal anti-inflammatory drugs as many of these may have detrimental side effects for the elderly. In this patient population, benzodiazepines should be avoided given their deliriogenic nature. Antihistamines and other medications that have anticholinergic components should also be avoided perioperatively. Routine testing is not recommended for all patients; however, in the geriatric population, it is advised to acquire a baseline hemoglobin, renal function, and albumin. These help provide anesthesiologists with information that is essential for managing patients' perioperative hemodynamics, proper medication dosing, and liver function/nutritional status.

General Anesthesia

The type of anesthesia chosen for the orthopedic trauma patient depends on a number of factors including patient age, preexisting medical conditions, other injuries, urgency, surgical procedure, and patient preference. General anesthesia usually includes volatile gases (e.g., isoflurane, sevoflurane, or desflurane), with or without nitrous oxide, but can also be provided using a total intravenous anesthesia (TIVA) technique. An endotracheal tube (ETT) or laryngeal mask airway (LMA) is typically placed to facilitate gas exchange with a ventilator. Under general anesthesia, the patient is unconscious and has no awareness or other sensations and is monitored, controlled, and treated by the anesthesia provider [25]. Unlike the LMA, ETT provides a secure airway and prevents aspiration of gastric content. An advantage of general anesthesia is greater control of the patient, especially if the patient decompensates during the surgery. In comparison to regional anesthesia, induction of general anesthesia is more predictable. Once an ETT is placed, the airway is under control, and invasive monitoring is more easily performed, such as placement of an arterial line, central venous pressure line, or pulmonary artery catheter. In addition, complete muscle relaxation can be achieved with general anesthesia when an ETT is used, which may be beneficial to the orthopedic surgeon. However, establishing and maintaining an airway are always a potential problem, and extra caution must be exercised for patients who have a history of difficult intubation or features which suggest they may be difficult to either mask ventilate or intubate. The large hemodynamic changes and myocardial depressant effects associated with general anesthesia put the elderly patient with heart disease at risk for a myocardial infarction or cerebral vascular accident [26]. In addition, a patient with a history of COPD may be difficult to extubate, resulting possibly in prolonged ventilatory support and the associated complications [27, 28].

Regional Anesthesia

Regional anesthesia can be used as an alternative to general anesthesia, supplement general anesthesia, or provide postoperative analgesia. The following is a discussion of the basic regional anesthesia techniques used for orthopedic trauma surgery. These techniques are broadly categorized into two groups: (1) neuraxial and (2) peripheral nerve blockade. In both cases, the procedures are done as either a single injection of local anesthetic with or without adjuvants or a placement of an infusion catheter for prolonged analgesia via a continuous infusion. During regional anesthesia, the patient may be awake or sedated.

Neuraxial Anesthesia

Neuraxial anesthesia consists of spinal and epidural anesthesia. A catheter can be placed in the spinal space (intrathecal) which can be used as a continuous spinal, but more often spinals are done as a single injection. A spinal usually provides blockade of both lower extremities. Spinal anesthesia sets up faster and provides a greater degree of motor blockade (muscle relaxation) than epidural anesthesia. In contrast, epidurals are often used with catheters so that continuous analgesia can be provided for several days. Epidurals produce a more gradual block and subsequently can be titrated to maximize pain relief while minimizing side effects such as hypotension. In addition, epidurals are placed in the lumbar region (pelvic or lower extremity trauma) or in the thoracic region (chest trauma). Combined spinal epidural anesthesia takes advantage of both neuraxial techniques. The spinal anesthesia is used to provide rapid onset of a dense motor block. This is followed by placing an epidural catheter that is utilized to extend the analgesia. Complications of spinals and epidurals include hypotension, urinary retention, headache, infection, and spinal hematoma.

In their most current Cochrane meta-analysis, Guay and colleagues compared the effect of regional anesthesia and general anesthesia on the mortality and morbidity of hip fracture surgery. They examined 31 randomized controlled trials (RCT) involving 3231 elderly hip fracture patients [29]. The primary outcome was mortality, which was evaluated at 1 month, 3 months, 6 months, and 12 months. These authors originally published an analysis reviewing the available data prior to 2004 and concluded that regional anesthesia was a borderline significant in reducing mortality at 1 month [30]. Despite these early conclusions, the authors updated their meta-analysis in 2016 to include over a dozen additional RCTs that had been published since their last review. The authors have since concluded that there is no longer statistical significance for an improvement in 1-month mortality (RR 0.78, 95% CI 0.57–1.06). They never found a difference in mortality at 3 months, 6 months, or 12 months after surgery, and this result did not change after repeat review. There was no statistically significant improvement in outcomes pertaining to pneumonias, myocardial infarctions, cerebrovascular accidents (CVA), or acute confusional states between regional and general anesthesia. There was also no difference between groups for regional anesthesia which was associated with a reduced risk of deep venous thrombosis (DVT) only when pharmacologic prophylaxis was not utilized (RR 0.57, 95% CI 0.41–0.79). For patients receiving low-molecular-weight heparin, there was no difference between groups (RR 0.98 CI 0.52–1.84). A significant weakness of this meta-analysis is that a number of the studies are more than 20 years old, and a handful of these studies do not represent the current practice of surgery and anesthesia. For example, pharmacological thromboprophylaxis is more widely used today, and benzodiazepines are actively avoided in the elderly.

A systematic review compared the effect of neuraxial and general anesthesia for hip fracture repair [31]. A total of 56 studies (8 reviews, 34 randomized control trials, and 14 observational studies) involving 18,715 patients were reviewed. Conclusions were based on weighing the evidence of the studies, but no statistical data were presented. Spinal anesthesia in comparison to general anesthesia was associated with reduced early mortality, fewer incidents of DVT, less acute postoperative confusion, and fewer cases of pneumonia, fatal pulmonary embolism, and postoperative hypoxia. General anesthesia had the advantage of having a lower incidence of hypotension and a tendency toward fewer cerebrovascular accidents compared to neuraxial anesthesia. The data suggested that regional anesthesia was the preferred technique, but a definitive conclusion could not be drawn for long-term mortality and other outcomes.

Rodgers and colleagues performed a meta-analysis: 141 randomized clinical trials in 9559 patients who received or did not receive neuraxial blockade were reviewed [32]. Neuraxial blockade was associated with reduced 30-day mortality (2.1% vs. 3.1%). Additionally, neuraxial blockade reduced the odds of DVT by 44%, pulmonary embolism by 55%, transfusion requirement by 50%, pneumonia by 39%, and respiratory depression by 59% (all $p<0.001$). The authors recommended more widespread use of neuraxial blockade. However, there was no attempt to limit trials to a specific adult population (e.g., hip fracture), surgical procedure, or anesthetic goal (e.g., intraoperative anesthesia, postoperative pain control). Therefore, applying their overall conclusion to all patients could be misleading [33]. In assessing benefit versus risk, consideration should be given to the patient population, surgical procedure, and anesthesia practice.

There are several reports that suggest that better medical management of hip fracture patients improves surgical outcome. For example, a prospective, observational study was designed to study the effectiveness of a hip fracture service [34]. Over an 11-year period, 2846 hip fracture patients were assigned to receive care from specific staff, and early discharge to community nursing was encouraged. Mortality at 30 and 120 days after fracture decreased from 21% and 35% (study launch in 1986) to 7% and 15% (study end in 1997), respectively. Therefore, the overall therapeutic approach for hip fracture care should be multidisciplinary, determined by the geriatrician, orthopedic surgeon, and anesthesiologist.

Peripheral Nerve Blockade

Peripheral nerve blocks include upper and lower extremity blocks (Fig. 32.3). The blocks may be performed as a single injection or with the placement of a peripheral nerve catheter (continuous peripheral nerve block). Peripheral nerve blocks are performed using ultrasound, nerve stimulation, or paresthesias. Ultrasound directly visualizes nerves and adjacent structures to precisely place local anesthetic to produce the blockade. Nerve stimulation is an anatomic or landmark-based technique that relies on a motor response elicited by a nerve stimulator to determine the injection point. With the paresthesia technique, the injection needle directly contacts the targeted

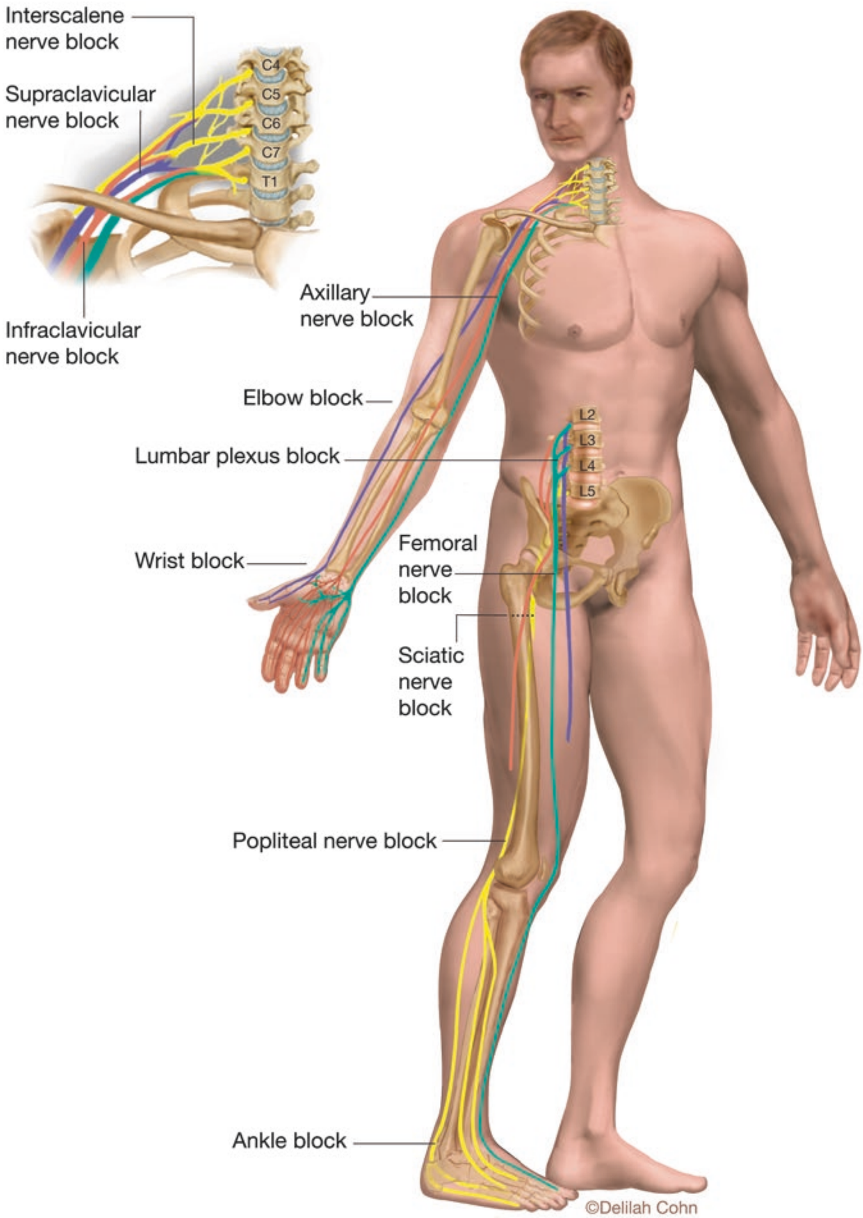

Fig. 32.3 Upper and lower extremity peripheral nerve blocks (Copyright © 2011 Delilah Cohn. Used with permission)

nerve, and the resulting paresthesia is used as the endpoint for injection. All the techniques use safety steps to prevent intraneural or intravascular injection. Although rare, major complications of regional anesthesia include nerve injury and local anesthetic systemic toxicity.

Upper extremity blocks consist of brachial plexus, elbow, and wrist blocks. The brachial plexus blocks include interscalene, supraclavicular, infraclavicular, and axillary nerve blocks. Lower extremity blocks consist of the lumbar plexus block, femoral, sciatic, popliteal, and ankle blocks. In contrast to the brachial plexus of the upper extremity, there is no single plexus that provides innervation to the lower extremity. Instead, the lumbar and sacral plexuses provide this function. Thus, more than one block is required to provide complete coverage of a lower extremity.

The lumbar plexus block alone and a combined lumbar plexus-sciatic nerve block have been successfully used to provide anesthesia for hip fractures [35–37]. One advantage of peripheral nerve blockade is only one extremity is anesthetized. The blockade usually lasts longer than single-injection neuraxial anesthesia because a larger volume of local anesthetic is used. Also, there is probably a lower incidence of hypotension. However, peripheral nerve blockade is not as reliable in producing a surgical block as spinal or general anesthesia. In addition, bleeding risk is still a concern in anticoagulated patients undergoing deep peripheral nerve blockade such as the lumbar plexus block [38]. Few studies in the literature compare these techniques to general anesthesia or spinal anesthesia, but two examples follow. In a prospective study, 60 patients received general anesthesia or a combined lumbar plexus-sciatic nerve block. The regional group had a lower incidence of intraoperative hypotension and reduced need for postoperative ICU care [36]. In a prospective, randomized trial, 29 patients received either spinal anesthesia or a combined lumbar plexus-sciatic nerve block [37]. Four patients in the lumbar-sciatic group had either an incomplete or failed block. Hypotension occurred in both groups but was more profound and prolonged in the spinal group.

Literature Inconsistencies

The available meta-analyses and systematic reviews utilize a number of the same studies, which results in similar conclusions. The literature does not consistently show a correlation between the mortality risk and any particular anesthetic technique. Overall, the 1-month mortality appears to be less with regional anesthesia than general anesthesia. However, this advantage was not maintained long term.

Evidentiary Table and Selection of Treatment Method

The key studies for managing KN are noted in Table 32.3 [29, 31, 32]. Based on the literature, the authors believe that the ideal intraoperative

Table 32.3 Evidentiary table: A summary of the quality of evidence for neuraxial anesthesia versus general anesthesia for an elderly hip fracture patient. (*RCT* randomized controlled trial, *DVT* deep vein thrombosis, *CVA* cerebral vascular accident)

Author (year)	Description	Summary of results	Level of evidence
Guay et al. (2016) [29]	Meta-analysis	31 RCTs, 3231 patients, neuraxial anesthesia did not reduce 1 month mortality, CVAs, or acute postoperative confusion. Neuraxial anesthesia only reduced DVT when pharmacologic prophylaxis was not used	II
Luger et al. (2010) [31]	Systematic review	34 RCTs, 14 observational studies, 8 reviews, 18,715 patients, spinal anesthesia reduced early mortality, DVTs, acute postoperative confusion, pneumonia, fatal pulmonary embolisms, and postoperative hypoxia; general anesthesia reduced hypotension and CVAs	II
Rodgers et al. (2000) [32]	Meta-analysis	141 RCTs, 9559 patients, neuraxial anesthesia reduced mortality by 33% and odds of DVT by 44%, pulmonary embolism by 55%, transfusion requirements by 50%, pneumonia by 39%, and respiratory depression by 59% (all $p < 0.001$)	I

management strategy for this patient given her age and comorbidities would likely be a spinal anesthetic.

Definitive Treatment Plan

Preoperative evaluation for KN should include a complete history, vital signs including oxygen saturation and auscultation of heart/lungs, and laboratory tests (glucose, electrolytes, BUN, creatinine, hemoglobin/hematocrit, and platelets) and coagulation studies. An ECG and chest radiograph should be performed for further evaluation of cardiac and pulmonary function. Depending on the cardiac findings, an echocardiogram may be indicated as previously described.

The anesthetic of choice for KN is a spinal anesthetic. However, the patient's coagulation studies need to be normal or corrected to normal [38]. The spinal anesthetic could be combined with light sedation for the surgery, preserving hemodynamic stability and pulmonary function. If neuraxial anesthesia could not be performed, general anesthesia would be a safe alternative. The goal of general anesthesia would be to preserve hemodynamic stability during ETT placement and throughout the surgery. Hip fracture surgeries are typically short, but if a prolonged anesthetic is anticipated, additional monitors may be useful such as an arterial line. Glucose should be checked prior to the surgery as well as during the surgery with intraoperative management as needed. Glucose should also be checked in the recovery room [39]. Multimodal therapy can facilitate postoperative pain control and reduce the adverse effects of opioids [40]. Excellent pain control is paramount for this patient population's comfort and safety.

Predicting Long-Term Outcomes

In a meta-analysis of 39 prospective cohorts with over 700,000 patients, elderly patients had a five- to eightfold increased risk for mortality in the first 3 months after a hip fracture [4]. Higher than average mortality risk decreased during the first 2 years after fracture but did not return to the rate of gender- and age-matched controls, even after 10 years of follow-up. The mortality risk increased with age and, at any given age, was higher for men than for women. Mortality for elderly hip fracture patients is multifactorial with comorbid conditions being a significant factor. However, preoperative optimization, early surgery (<48 h), and good postoperative care may improve long-term outcomes.

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33 Management of Acute Postoperative Infection

Frank R. Avilucea

AA: A 33-Year-Old Male with Knee Pain

Case Presentation

AA is a 55-year-old type-2 diabetic male who initially presented to the emergency department (ED) following a motorcycle accident. At the time of assessment in the ED, he reported isolated right knee pain. On primary survey, he was noted to be hemodynamically stable with a GCS score of 15. Secondary survey demonstrated significant swelling at the knee, no gross deformity in any limb, and the absence of any cutaneous abrasions or lacerations. Radiographs of AA's knee demonstrate an isolated lateral split-depression tibial plateau fracture. Management of the injury was treated in a staged manner involving placement of a knee-spanning external fixator followed by open reduction internal fixation (ORIF) following resolution of soft-tissue swelling. At the 2-week follow-up office visit, AA reports knee pain with associated redness and discolored drainage from the surgical site.

F. R. Avilucea (✉)
Department of Orthopedic Surgery, Division of Orthopedic Trauma, University of Cincinnati Medical Center, Cincinnati, OH, USA
e-mail: avilucfr@ucmail.uc.edu

Physical examination in the office demonstrates erythema along the entire length of the laterally based incision. There is purulent discharge at the surgical site; patient has no pain with passive range of motion of the knee, and sensation to light touch is intact in all dermatomal distributions. Dorsalis pedis and posterior tibialis pulses are palpable and equal to the contralateral extremity. All leg compartments are soft, and there is no pain with passive range of motion of the ankle or toes.

Laboratory values demonstrate a white blood cell count (WBC) of 16 and C-reactive protein (CRP) level of 115 mg/dl. Radiographs of the left knee are demonstrated in Figs. 33.1a, b and 33.2a, b.

Interpretation of Clinical Presentation

This patient's findings and symptoms are consistent with an acute infection following surgical treatment. The history of recent surgical repair of a closed lateral tibial plateau fracture with subsequent erythema, drainage, and elevated serologic markers heightens suspicion for acute postoperative infection.

Early wound colonization by bacteria is the first step leading to acute infection following surgery. The bacteria may colonize the surfaces of the bone and implant at the fracture site or just the more superficial wound. The depth of infec-

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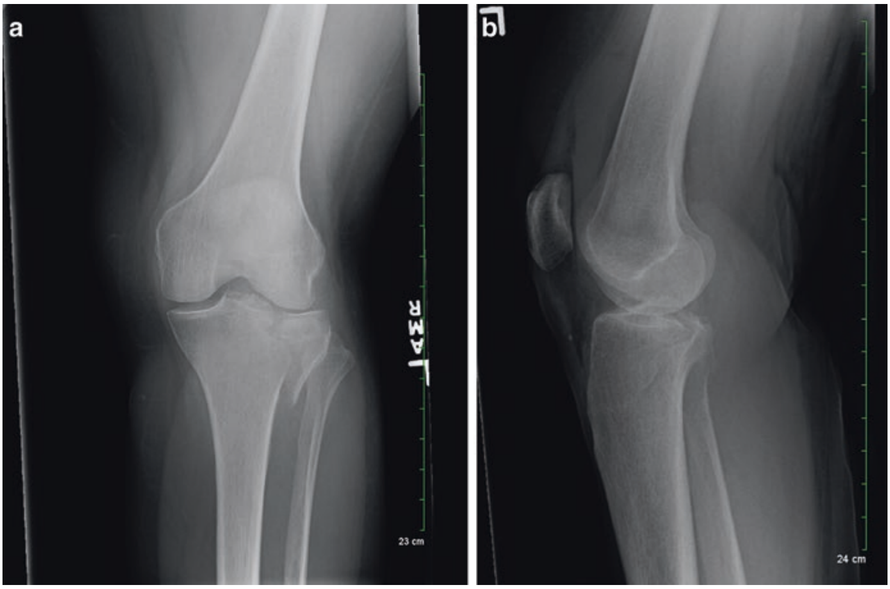

Fig. 33.1 (**a**) AP Radiograph of the left knee (**b**) Lateral Radiograph of the left knee

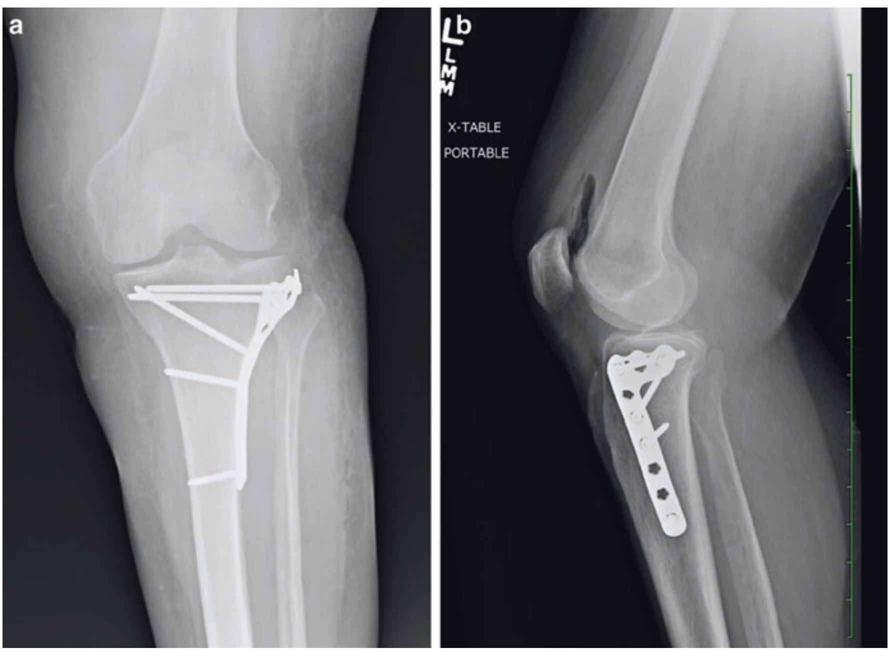

Fig. 33.2 (**a**) Postoperative AP radiograph of the left knee (**b**) Postoperative lateral radiograph of the left knee

tion may be challenging to immediately specify, particularly as the long bones of limbs are encased in several layers (muscle, fascia, and skin), many of which have varied thickness depending on the anatomic location. The distinction between a superficial and deep infection is important: a superficial wound infection may only require repeat debridement and antibiotics, while a deep infection may be concerning for osteomyelitis requiring possible implant removal. At present, guidelines about surgical site infections (SSIs) distinguish superficial SSIs, which affect the incision but do not extend to the fracture site, and deep SSIs, defined as an infection to the bone at the fracture site [1]. Both the anatomic relationships of the fracture site and the fixation technique used play a significant role in the course of superficial SSIs. Consequently, when the fracture site is located immediately beneath the subcutaneous tissue and the implanted fixation lacks a superficial layer of tissue, spread of infection beyond the superficial plane is likely.

Both the clinical and bacteriological features of SSI following ORIF (SSI-ORIF) require specific attention as there are three main clinical presentations:

1. Purulent discharge from the surgical site and/or incision with or without an associated erythema, tenderness, or fever
2. Fever with non-specific local symptoms (local or regional pain, swelling, or joint stiffness)
3. Absence of radiological evidence of fracture union after several months, with or without fixation failure

Serologic abnormalities may be suggestive but none are specific for SSI. In the early postoperative period, biomarkers associated with activation of the systemic inflammatory response, such as serum C-reactive protein (CRP), are expected to be elevated. The change in CRP over time is more helpful than the absolute value [2]. It is necessary to note, however, that many SSIs occur without any hematologic or serologic abnormalities. Olszewski and colleagues retrospectively reviewed 666 consecutive nonunions where 453 were considered high risk for infection with cultures taken at time of surgery. Ninety-one of these cases had a "surprise" positive intraoperative culture despite negative inflammatory markers with most of the cultured bacteria isolated from the *Staphylococcus* species [3].

Imaging studies are also of limited value during the first few weeks of infection, as they may fail to show changes over time that may appear in chronic infections. Computed tomography and ultrasound, however, may enable visualization of a deep fluid collection (or air) around the bone and guide needle aspiration or surgical intervention.

The definitive diagnosis of SSI-ORIF requires identification of a microorganism within the surgical site. The presence of a microorganism is the only objective finding that differentiates infections from healing disorders. As a result, scrupulous technique must be used when collecting samples. Swabs are not reliable because surgical incisions and traumatic lacerations are typically contaminated by the local flora [4]. Specimens may be collected by several methods, including needle aspiration or formal surgical biopsy. The number of samples required to optimize diagnosis of SSI-ORIF remains to be elucidated; five are recommended and the collection of three tissue samples from sites spaced as far apart as possible is acceptable. In such a setting, the surgeon should notify the laboratory of the patient's clinical details and request that cultures be maintained for a prolonged period of time if a slow-growing organism is suspected (i.e., *P. acnes*).

Definitive diagnosis is often established when an organism is recovered from samples taken from sites in contact with hardware and/or the deepest portion of the surgical approach although infection may be present when organisms are not recovered. A study by Gitajn and colleagues studied 391 patients, comparing the outcomes of patients with culture-negative infection to those with culture-positive identified pathogens [5]. Overall, 9% of the cases had infection, although cultures were negative at the time of surgery. Interestingly, 25% of patients on pathogen-specific antibiotics and 38% of culture-negative patients went on to treatment failure. In this study, there was no difference in union time between groups. More than one-third of patients required subsequent reconstructive surgery and approximately 5% of patients in each group required amputation. This study concluded that with clinical signs of infection, negative cultures do not portend a better prognosis and should be treated similarly to culture-positive patients [5].

Initial management of a patient with a suspected SSI after operative repair of a fracture consists of measuring patient temperature for presence of fever and obtaining a CRP level and complete white blood count with differential to assess presence of leukocytosis. Stucken and colleagues studied fracture nonunions complicated with infection, looking at white cell count, ESR, and CRP as risk factors. The predicted probabilities of having an infection for 0, 1, 2, and 3 of these risk factors were 20%, 19%, 56%, and 100%, respectively [6].

Declaration of Specific Diagnosis

This patient's findings and symptoms are consistent with an acute infection following surgical treatment.

Brainstorming: What Are the Treatment Goals and Options?

Treatment goals consist of the following objectives:

1. Infection control and eradication
2. Provide fracture stability to enable osseous union
3. Allow for continued knee motion to prevent arthrofibrosis

Treatment options include the following:

1. Conservative management
2. Irrigation and debridement(s) and hardware retention
3. Irrigation and debridement(s) and removal of hardware

Evaluation of the Literature

To identify relevant publications on acute postoperative infection, electronic Medline and PubMed searches were performed. Keywords included the following: "postoperative infection" and "fracture fixation". All searches were limited to publications from January 1, 1975, to 2017, English language, human subjects, and chronological adults (> 19 years of age). This search identified 645 abstracts that were reviewed. From this, 86 publications were read and their reference lists were reviewed.

Detailed Review of Pertinent Articles

Bacterial Pathogenesis/Biofilm

Implanted surgical devices represent substrates for microbial colonization and biofilm-related infection. A wide variety of pathogens have been associated with indwelling medical devices including *Staphylococcus*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, and *Escherichia coli*; these can originate from commensal flora or be hospital-acquired. Postoperative colonization of surgically implanted devices can occur as a result of bacteremia or from direct inoculation during the actual surgical procedure.

Bacteria located at sites of injury are initially free-floating (planktonic). This represents the inoculation phase of infection. Due to their high metabolic rate, planktonic bacteria are particularly sensitive to antibiotics. In the absence of effective treatment, bacteria settle into a mature biofilm (sessile phase) and develop an attenuated metabolic rate and growth cycle, permitting a lengthened generational cycle from hours to a day. Within a mature biofilm, so-called persister cells exist and comprise approximately 1% of the cell population. These particular cells are essentially dormant, multidrug tolerant, and have the ability to repopulate the biofilm colony [7, 8]. Finally, within a biofilm, there are chemomodulators known as quorum-sensing molecules that permit intercellular communication within the biofilm network, even among different species of bacteria, and promote bacterial resistance.

Biofilms develop in an organized manner that begins when planktonic cells adhere to an appropriate surface, typically a foreign material such as an implant or, in the setting of trauma, at the site of devascularized bone or soft tissue. The process is rapid and often proceeds within minutes. Following nonreversible adherence, an organized construction of biofilm mediated by short generational cycles and rapid cell multiplication ensues. At present, it remains unclear how soon a mature biofilm is established; however, the process is likely in the range of several weeks.

It is necessary to understand the interplay that a bacterial biofilm has with its host, an interaction that enables such an infection to either remain quiescent or evolve to manifest in local and systemic signs. At present, there is no classification system that may be utilized to guide treatment. Like the Cierny-Mader staging system for osteomyelitis [9], an acute postoperative infection should be given similar considerations including the degree of bone that is potentially involved in the infection and the condition of the host. As such, modifiable risk factors including obesity, nutritional diabetes, rheumatoid arthritis, immunosuppressive agents, nicotine use, alcohol abuse, intravenous drug abuse, and *S. aureus* colonization may be potentially addressed to optimize treatment [10, 11].

Maintenance of Hardware

When treating an infected nonunion, a challenging question faced by the treating surgeon is whether to maintain the fixation that is stabilizing the fracture. Based upon the abundant information within the arthroplasty literature, it is evident that any form of treatment cannot engender full recovery without concomitant surgical intervention [12–16].

One approach to treating early postoperative infection associated with fracture nonunion is to remove the implant, eradicate the infection by performing surgical debridement and prolonged antibiotics, and then proceed with revision surgery. Another approach would be to perform irrigation and debridement with maintenance of fixation, with provision of suppressive antibiotics therapy. Currently, there are no prospective studies comparing the outcome of these treatment approaches.

Retrospective series demonstrate an overall success rate ranging from 68% to 71% with irrigation and debridement, maintenance of fixation, and concomitant culture-specific antibiotics [17, 18]. In one study, factors predictive of treatment failure included the presence of an intramedullary rod, smoking, and a *pseudomonas* infection [18]. Given the interplay among the host, biomaterial, and bacterial biofilm, it is necessary that a mechanical debridement of all visible hardware surfaces be completed. Additionally, removal of smaller foreign materials, such as bone wax, wires, and any devitalized tissue improves the likelihood of cure [19]. Assessing the stability of the implant at the time of debridement is a necessary factor as previous studies demonstrate that a stable implant is an important predictor of successful salvage [20, 21].

Additional situations in which removal of hardware in the early postoperative period (within 6 weeks of fixation) is warranted include soft-tissue infection unable to be debrided adequately without hardware removal, loose hardware, or fracture displacement. The presence of any of these factors impedes the ability to eradicate infection. When fracture fixation hardware is removed prior to fracture union, an alternative means of fracture stabilization must be chosen (e.g., revision internal fixation or external fixation) to maintain stability of the fracture site. Additionally, in the setting of soft-tissue loss, coverage of the affected site by a vascularized tissue is necessary.

PO Versus IV Antibiotics

Current treatment regimens practiced throughout North America and Europe require patients with postoperative infections to receive prolonged IV antibiotic therapy following surgical debridement. Prolonged IV therapy is associated with a substantial risk of line sepsis, tip occlusion, and vein thrombosis as well as other risks to the patient related to changes in the patient's gut microbiome [22]. In addition, parenteral antibiotic therapy is expensive and is not available to all patients due to cost and can be problematic in patients with a history of IV drug abuse or the potential for non-compliance with treatment recommendations.

Little data are available on infection after fracture fixation, but the total joint literature provides a reasonable comparison. Over the last decade, several studies [23–26] have demonstrated the efficacy of the oral fluoroquinolones, ciprofloxacin, and ofloxacin for the treatment of serious bone and joint infections. In 2000, the oral antibiotic linezolid was introduced. Linezolid is active against many of the so-called resistant organisms, including methicillin-resistant *Staphylococcus aureus* and *Enterococcus*. It is evident that there are now oral antibiotics that cover a wide range of typical pathogens encountered in orthopedics and that have acceptable penetration into the bone and joint fluid.

There is also extensive literature describing the successful use of oral antibiotic therapy for the management of adult and pediatric osteomyelitis [23–25, 27–30]. In a controlled clinical trial, Mader and colleagues [31] compared treatment with oral ciprofloxacin to intravenous nafcillin, clindamycin, and gentamicin in adult patients with chronic osteomyelitis. After 30 months of follow-up, infection was eradicated in eleven of fourteen patients (70%) treated with ciprofloxacin compared to ten of twelve (83%) who had IV therapy [31]. In another prospective, randomized study, 31 patients with osteomyelitis received oral ciprofloxacin (750 mg twice daily) and 28 were treated with IV cephalosporin or nafcillin-aminoglycoside combination [32]. The clinical success rate was 77% for the ciprofloxacin group compared to 79% for the IV group. Adverse drug reactions occurred in only 3% of the patients that received ciprofloxacin compared to 14% of the patients treated with IV antibiotics [32]. Swiontkowski and colleagues [33] showed in a case series that 6 weeks of oral antibiotic therapy with either trimethoprim-sulfamethoxazole or ciprofloxacin following thorough surgical debridement was successful in 80 of 93 cases (91%). Nearly a third of these patients had concomitant internal fixation of persistent bone defects. Oral antibiotic therapy is now considered appropriate for most cases of osteomyelitis caused by sensitive organisms [23, 30]. As the study by Swiontkowski and colleagues [33] shows, oral antibiotic therapy can also be successful in implant-related musculoskeletal infections, when combined with appropriate surgical treatment.

Several studies have reported that cost reductions are two- to tenfold when oral antibiotic therapy is employed as compared to intravenous therapy [23]. The cost of IV drug therapy includes the costs of placing and maintaining long-term venous access, as well as the cost of a medication pump or visiting nurse. These costs can range from $3500 to over $10,000 for a 6-week course of intravenous home antibiotics [34]. If one considers the additional cost of outpatient IV antibiotic delivery, the cost differential between oral and intravenous antibiotic use is even more profound. The total cost for outpatient IV antibiotic administration can range from $70 to $246 per day, compared to $7 per day for oral fluoroquinolones. The cost of linezolid, as a PO antibiotic effective against MRSA, is significant and can be $200–2000 for a 4-week course, although even this amount may compare favorably to IV therapy for a similar time period [35].

Antibiotic Choice and Duration

A prospective study on the efficacy and tolerability of linezolid for the treatment of orthopedic implant infections was performed on 85 patients [36]. For acute and chronic infections, the success rates were 100% and 92% when the implant was removed. When the implants were retained, the success rates dropped to 72.2% and 48%, respectively [36]. A pilot study by Euba et al. on the combination of ampicillin-ceftriaxone for the treatment of orthopedic infections due to *Enterococcus faecalis* indicates this combination treatment may be effective in eradicating infection [37]. This study included 31 patients with *Enterococcus faecalis* infection with 11 patients treated with ampicillin-ceftriaxone (3 prosthetic joint infections, 3 instrumented spine arthrodesis device infection, 2 with osteosynthesis device infection, 1 with foot osteomyelitis, and 2 with vertebral osteomyelitis and endocarditis). All cases but the two vertebral osteomyelitis cases required surgery with retention of the implant in six of the cases. One patient with a history of endocarditis died. One patient with the retained implant had persistent infection, while 9/10 were successfully treated [37]. A randomized controlled trial on the role of rifampicin for treatment of orthopedic implants infected with staphylococcal infections compared the combination of Cipro and rifampicin to Cipro alone. The cure rate of the combination Cipro-rifampicin was 100% (12/12) compared to 58% (7/12) in the group treated with Cipro alone [38]. A prospective review looking at the outcomes of infections associated with implants mimics these findings. In this study, 20/24 patients with retained implants were successfully treated (14 hip prosthesis, 5 knee prosthesis, 4 internal fixation device, and 1 ankle prosthesis), concluding that patients with a short-term implant, stable implant, no sinus tract, and a known pathogen can be successfully treated with retaining the implant and antibiotic treatment [39].

Evidentiary Table and Selection of Treatment Method

The key studies influencing treatment of AA are noted in Table 33.1 [3, 5, 6, 17, 18]. Based upon the timing of symptom onset following surgical intervention and the findings noted in the table, AA is optimally treated with irrigation and debridement, hardware retention, and antibiotics that are initially broad-spectrum and subsequently narrowed once bacterial speciation and sensitivities are completed. Antibiotics can be delivered PO or IV based on bacterial susceptibilities, physician, and patient factors with equal efficacy. The available literature supports this treatment algorithm to provide a high likelihood of successful treatment to achieve fracture union and avoid comorbid treatments involved with staged treatment.

Definitive Treatment Plan

In the case of AA, the best treatment based on available evidence would be a return to the operating room for debridement of the infection and all necrotic, devitalized tissue as well as any loose implant material such as bone wax and wires. While in the operating room, the implants need to be tested for mechanical stability. If the implants are stable and maintaining reduction, then the implants should be retained [20, 21]. Several deep tissue samples should be biopsied, taken as far from each other as possible during the debridement in order to be representative of the entire wound. These deep tissue samples are

Table 33.1 Evidentiary table: A summary of the quality of evidence for postoperative infection following fracture fixation

Author (year)	Description	Summary of results	Level of evidence
Rightmire et al. (2008) [17]	Retrospective	69 cases of postoperative infection within 16 weeks of fixation. Treatment included irrigation/debridement, retained hardware, and antibiotic suppression. 68% of patients achieved successful union	IV
Berkes et al. (2010) [18]	Retrospective	87 cases of postoperative infection within 6 weeks of fixation. Treatment included irrigation/debridement, retained hardware, and antibiotic suppression. 71% of patients achieved successful union (80% of plates and 50% of IMNs)	IV
Olszewski et al. (2016) [3]	Retrospective	666 consecutive nonunions where 453 were considered high risk for infection with cultures taken at time of surgery. 91 of these cases had a surprise operative culture despite negative inflammatory markers	IV
Gitajn et al. (2016) [5]	Retrospective	391 patients studied. 9% rate of culture-negative infection. 25% of pathogen-specific patients and 38% of culture-negative patients went on to treatment failure. 5% of patients in each group required amputation	IV
Stucken et al. (2013) [6]	Diagnostic	Studied fracture nonunions complicated with infection looking at white cell count, ESR, and CRP as risk factors. The predicted probabilities of having an infection for 0, 1, 2, and 3 of these risk factors were 20%, 19%, 56%, and 100%, respectively	III

needed to more accurately characterize the infection, since superficial swabs may only identify local flora. Along with debridement, organism-specific antibiotic therapy should be started postoperatively. If after debridement and antibiotics, the infection persists, then removal of hardware and placement of external fixation may be considered. The current standard for antibiotic treatment is IV, directed at the infecting organism(s). Recent literature suggests that oral antibiotics may be just as effective at a significantly reduced cost [21]. Oral antibiotics that have been shown to be successful to treat osteomyelitis include trimethoprim-sulfamethoxazole, ciprofloxacin, and linezolid [31, 33, 34].

Implants are salvageable in the face of infection. A prospective study on the outcomes of infections associated with retained implants found that 20/24 patients at 4 years were successfully eradicated of infection while retaining the implant. This study concluded that patients with a short-term implant, no sinus tract, and a known pathogen can be successfully treated by retention of the implant and antibiotics [39]. For AA, postoperative IV or oral antibiotics should be administered for at least 6 weeks followed by suppressive antibiotic therapy until the implant can be removed after fracture union is confirmed.

Predicting Outcomes

The outcome of a musculoskeletal infection is determined by many variables. These include the type of bacteria, whether any associated implant is retained, the type of antibiotic that is used, and the method that the antibiotic is delivered. A prospective study on the efficacy and tolerability of linezolid for the treatment of orthopedic implant infections was performed on 85 patients [36]. For acute and chronic infections, the success rates were 100% and 92% when the implant was removed. When the implants were retained, the success rates dropped to 72.2% and 48%, respectively [36].

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