Post-Traumatic Arthritis

Diagnosis, Management and Outcomes

Savyasachi C. Thakkar
Erik A. Hasenboehler
Editors

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ISBN 978-3-030-50412-0 ISBN 978-3-030-50413-7 (eBook)
https://doi.org/10.1007/978-3-030-50413-7

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

I would like to dedicate this book to my parents Mrs. Heena C. Thakkar and Dr. C.J. Thakkar for their dedicated upbringing and commitment towards excellence in life. I would also like to dedicate the book to my wife Dr. Rashmi S. Thakkar and my children Sahuri and Shaarav who have provided me with untiring support, love and patience. Without these individuals, I would not be where I am today!

Savyasachi C. Thakkar, MD

This book is dedicated to my beloved father Dr. Giorgio Hasenboehler, who passed years ago of cancer, and to my mother Elfriede Hasenboehler, whom have always supported me and have fostered my passion for medicine and the surgical specialty. I also would like to acknowledge my love Ana Torregrosa for her infinite support, and last my dearest children Nikolas and Lukas to whom this book shall be an example of commitment to teaching, learning and dedication to a fulfilling profession.

Erik A. Hasenboehler, MD

Preface

The incidence and prevalence of post-traumatic arthritis is increasing globally due to longevity of life, increased activity and injuries. Orthopaedic surgeons are skilled at treating traumatic injuries to the extremities and joints. Early anatomic stabilization is required when it comes to traumatic joint reconstructions. Unfortunately, post-traumatic osteoarthritis (PTOA) of a joint is an unpredictable consequence that can occur at any time, in different presentations, severity and complexity after an injury. Delayed post-traumatic complications require a thorough understanding of anatomic principles, meticulous planning and symphonic surgical execution. Timing of treatment and subsequent care of PTOA are the most essential aspects to achieve excellent outcomes in this challenging group of patients.

The book is broadly divided into two parts – upper extremity and lower extremity – to encompass the breadth of the subject while delving into the unique challenges of each joint. Additional parts of the book will also cover the basic science of cartilage degeneration in response to trauma, dedicated imaging modalities that optimize visualization and surgical planning of the arthritic joint and the economic impact of post-traumatic osteoarthritis.

It is our hope that the readers of this book will receive a comprehensive framework to base their clinical decisions and learn about the latest techniques in managing these challenging injuries. The book is geared towards general orthopaedic surgeons and sub-specialty trained orthopaedic surgeons with equal measure. The book has also been written for orthopaedic surgeons in training who require a broad overview of this subject to complement their education.

This book would not have been possible without the tremendous synergy between basic science experts, radiologists and orthopaedic surgeons with a passion for teaching by example. On behalf of the editors and the authors, we hope that you enjoy reading this book and apply the principles of managing post-traumatic osteoarthritis for the benefit of your patients.

Columbia, MD, USA Savyasachi C. Thakkar
Baltimore, MD, USA Erik A. Hasenboehler

Acknowledgments

The creation of this book has been a collective effort of several professionals. First, we would like to thank the authors who have provided us their invaluable time and energy to assemble various surgical cases that highlight the sentinel principles of post-traumatic arthritis. Second, we would like to acknowledge Ms. Meera V. Shanbhag who has devoted her talents as a pre-medical student at Vanderbilt University in reviewing manuscripts and collating the contents of this book.

Third, this book would not have been possible without the oversight and planning provided by Mr. Kristopher Spring and Ms. Abha Krishnan. Both of them have provided us with tremendous resources to make this book a reality.

Finally, we would like to thank our families for providing us with incredible support and motivation to devote time to projects such as this.

Contents

Part I Background and Assessment of Post-traumatic Arthritis

1 The Role of TGF-β in Post-traumatic Osteoarthritis 3
Gehua Zhen and Xu Cao

2 Imaging Modalities for Post-traumatic Arthritis 15
Filippo Del Grande, Luca Deabate, and Christian Candrian

3 Economic Implications of Post-traumatic Arthritis of the Hip and Knee 25
Richard Iorio, Kelvin Y. Kim, Afshin A. Anoushiravani, and William J. Long

Part II Post-traumatic Arthritis of the Upper Extremity

4 Post-traumatic Glenohumeral Arthritis 45
Uma Srikumaran and Eric Huish

5 Post-traumatic Arthritis of the Elbow 59
Kevin O'Malley, Ryan Churchill, Curtis M. Henn, and Michael W. Kessler

6 Post-traumatic Arthritis of the Wrist 73
Sophia A. Strike and Philip E. Blazar

7 Post-traumatic Arthritis of the Hand 97
Andrew P. Harris, Thomas J. Kim, and Christopher Got

Part III Post-traumatic Arthritis of the Lower Extremity

8 Post-traumatic Arthritis of the Acetabulum 111
Savyasachi C. Thakkar, Erik A. Hasenboehler, and Chandrashekhar J. Thakkar

9 Post-traumatic Arthritis of the Proximal Femur 135
Raj M. Amin, Erik A. Hasenboehler, and Babar Shafiq

10 Post-traumatic Arthritis of the Distal Femur 153
Karthikeyan Ponnusamy and Ajit Deshmukh

11 Post-traumatic Arthritis of the Proximal Tibia 167
Stefanie Hirsiger, Lukas Clerc, and Hermes H. Miozzari

12 Post-traumatic Arthritis of the Ankle 185
Nigel N. Hsu and Lew Schon

13 Post-traumatic Arthritis of the Foot 199
Ram K. Alluri and Eric W. Tan

Index 219

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Part I
Background and Assessment of Post-traumatic Arthritis

Chapter 1
The Role of TGF-β in Post-traumatic Osteoarthritis

Gehua Zhen and Xu Cao

Key Points

- Osteoarthritis is a disease that affects the whole joint. Biochemical and biomechanical interactions among different components within the joint actively participate in and contribute to the development and progression of the disease.
- TGF-β plays an important role in the pathogenesis of osteoarthritis. Temporal and spatial regulation of TGF-β activity is critical for maintenance of homeostasis of joint tissues.
- The effects of TGF-β differ according to tissue type within the joint and may vary at different time points. Various tissue-specific treatments targeting TGF-β signaling may produce optimal therapeutic effects.

Introduction

Osteoarthritis is the most common degenerative joint disease. Although osteoarthritis develops in joints naturally over time, it progresses rapidly after traumatic injury. Extreme physical demands or injuries to bones, ligaments, menisci, or articular cartilage predispose patients to post-traumatic osteoarthritis (PTOA) [1]. Despite surgical reconstruction of the joint components, osteoarthritis still develops at a high rate after joint injuries. PTOA accounts for an estimated 12% of all cases of osteoarthritis, with approximately 5.6 million people in the United States living with PTOA [2]. The symptoms of PTOA, including joint pain, swelling, stiffness, and

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_1

limited movement, are similar to symptoms of other types of osteoarthritis. The pathological characteristics of PTOA include articular cartilage degeneration, abnormal bone formation, and aberrant angiogenesis in subchondral bone.

The risk of developing PTOA can be minimized by preventing injuries to the joint. According to osteoarthritis management guidelines, treatment of PTOA often starts with lifestyle modifications, including weight loss, low-impact exercise, and strengthening of the muscles surrounding the joint [2]. Analgesics and anti-inflammatory medications are the primary nonsurgical approach to control symptoms. However, these medications can cause gastrointestinal complications and their efficacy quickly becomes blunted. To date, there is no approved pharmacologic agent, biologic therapy, or procedure to prevent progressive destruction of the osteoarthritic joint. Many agents have been developed and tested to treat osteoarthritis-related abnormalities. Glucosamine sulfate, chondroitin sulfate, sodium hyaluronan, and matrix metalloproteinase (MMP) inhibitors have been tested in various clinical trials [3]. Unfortunately, the ability of these medications to stop or reverse osteoarthritis progression is still limited. In end-stage PTOA, when medications are no longer effective to control symptoms, surgical treatment such as arthroscopic debridement, reconstruction, or joint replacement is usually necessary.

A new treatment paradigm relies heavily on novel findings in pathogenesis studies. Progress in exploring new biologic and pharmaceutical interventions has been impeded because the pathomechanical cause of PTOA is still poorly understood. Currently, most patients in the United States receive appropriate surgery and/or physical therapy immediately after an acute joint injury. However, PTOA develops eventually in a considerable proportion of these patients. Surgical reconstruction may not fully restore normal joint kinematics, causing an altered mechanical environment that may lead to secondary cartilage degeneration and joint abnormalities [4]. Osteoarthritis risk factors such as obesity, aging, and joint malalignment accelerate decline of joint function. These factors directly or indirectly change the mechanical environment of the joint after traumatic injury. This evidence collectively indicates that chronic alteration of mechanical stress could be the one of the primary triggers of PTOA onset and progression. Because osteoarthritis affects the whole joint, changes in biochemical and/or biomechanical properties of one tissue may influence the homeostasis and integrity of other parts of the joint.

The Functional Unit of Articular Cartilage and Subchondral Bone

Recently, patient-specific finite element stress analysis has been used to measure cartilage stress from residual surface incongruity after traumatic joint injury. However, factors that trigger stress alterations in cartilage are not limited to cartilage itself. As a functional unit, the joint involves constant interaction between various tissues [5]. Because of the physical contact between cartilage and bone, the mechanical influence of the subchondral bone on articular cartilage is critical to the maintenance of cartilage homeostasis. Articular cartilage buffers loading force and prevents mechanical damage to subchondral bone, while subchondral bone provides structural support for the overlying articular cartilage. Thus, the homeostasis and integrity of these two tissues rely on the biochemical and biomechanical interplay between them [5]. A finite element simulation study indicated that slight expansion of subchondral bone volume or elevation of subchondral bone stiffness dramatically increases the mechanical stress in the overlying articular cartilage [6]. Subchondral bone responds rapidly to changes in the mechanical environment, and its structural changes can be detected during the early stages of osteoarthritis. When the ability of subchondral bone to provide stable mechanical support is impaired, one would expect the stress distribution in articular cartilage to alter accordingly. The mechanical impact of subchondral bone on articular cartilage is translated into biochemical signals that influence cartilage homeostasis [7]. Therefore, exploring how subchondral bone responds to an abnormal environment and how it subsequently affects cartilage homeostasis is critical to understanding the pathogenesis of PTOA.

To maintain proper levels of calcium and phosphorus in circulation and reshape the micro-damage that occurs during normal activities, adult bone is constantly resorbed and formed in a process called bone remodeling. To provide stable support to the overlying cartilage, normal subchondral bone maintains the turnover rate at a very low level compared with that of the long bone trabeculae. However, the bone turnover rate increases dramatically in osteoarthritic subchondral bone [8]. The sequence of events that occurs in normal bone remodeling is disrupted, and the discordant behavior of osteoblast and osteoclast lineage cells results in abnormal bone formation with hypo-mineralization. The de novo bone formation in the osteoarthritic subchondral bone suggests that the new bone does not form in the resorption pit of the bone surface but rather in the bone marrow cavity, without appropriate connections to the original trabeculae. Understanding the mechanism that underlies the uncoupled bone resorption and formation is imperative for developing effective measures to mitigate subchondral bone abnormality and consequent cartilage degeneration. In the osteoarthritic environment, particularly during adaptation to the new mechanical environment, subchondral bone is destroyed by highly activated osteoclasts. Consequently, high levels of active transforming growth factor-β (TGF-β) are released from the sequestration of bone matrix, triggering sequential pathological events at the onset and during the progression of osteoarthritis [6].

TGF-β

TGF-β is a cytokine that belongs to the TGF-® superfamily, members of which have been highly conserved through evolution and are involved in a broad range of biological processes [9]. TGF-β is one of four major subfamilies of this superfamily. There are three TGF-β isoforms: TGF-β1, TGF-β2, and TGF-β3. These isoforms have distinct tissue-specific expression profiles but use the same receptor-signaling systems [10]. On secretion, the homodimers of mature TGF-β peptide link noncovalently to latency-associated peptide (LAP), with LAP masking its receptor-binding domains and rendering it inactive [11]. The small latent complex formed by LAP and TGF-β further interacts with latent TGF-β binding protein in the extracellular matrix and forms the large latent complex. Although TGF-β synthesis is widespread, activation is localized to sites where TGF-β is released from latency. Temporal-spatial regulation of TGF-® activation is crucial for appropriate function of this cytokine, and the abundant latent TGF-®s that are deposited in the extracellular matrix ensure that sufficient TGF-β can be activated when necessary. The TGF-β activation mechanism is tissue-specific and cellular context-dependent [12]. For example, enzyme-mediated proteolytic cleavage has been reported to be the dominant pathway for TGF-β to be activated in tumors or metastasis, whereas pulmonary fibrosis is induced by integrin-mediated excessive TGF-β activation. Multiple mechanisms of TGF-β activation may be used or switched from one to another depending on the cellular context or environmental stimuli [11].

TGF-βs signal via the heteromeric complexes of two related transmembrane serine/threonine kinase receptors, TGF-β type I and type II receptors (TβR-I and TβR-II). TβR-I is also termed activin receptor-like kinase (ALK). The dimeric ligand of TGF-β binds to the extracellular domains of TβR-I and TβR-II, inducing close proximity of the receptors. Unlike TβR-II, which is unique to its ligand, distinctive TβR-Is can be phosphorylated by TβR-II, which determines the specificity of the downstream signaling pathway [13]. Smad2 and Smad3 are substrates of ALK5, whereas ALK1 phosphorylates Smad1, Smad5, and Smad8. After phosphorylation by the receptor, the phosphorylated receptor-regulated Smad forms a complex with the common mediator Smad4 and translocates to the nucleus where they interact with other transcription factors (cofactors) to regulate transcriptional responses. In addition to the Smad-dependent canonical pathway, TGF-β also signals through the Smad-independent or noncanonical pathways. The tumor necrosis factor receptor-associated factor 4 (TRAF4), TRAF6, p38 mitogen-activated protein kinase (p38 MAPK), TGF-β-activated kinase 1 (TAK1; also known as MAP3K7), Ras homolog gene family, phosphoinositide 3-kinase (PI3K), protein kinase B, extracellular signal-regulated kinase (ERK), JUN N-terminal kinase (JNK), and nuclear factor-κB (NF-κB) have all been reported to mediate the TGF-β signaling pathway [14].

The Role of TGF-β in Osteoarthritic Subchondral Bone

Temporal-spatial regulation of the TGF-β activation process is the prerequisite for TGF-β to function appropriately. Additionally, the effect of TGF-β is influenced by the expression levels and activity of TGF-β receptors, as well as downstream factors. When TGF-β signaling is up- or downregulated, tissue homeostasis fails in the affected organs. Abnormal TGF-β signaling has been observed in various immune diseases, cancer, heart disease, diabetes, Camurati-Engelmann disease, Marfan syndrome, Loeys-Dietz syndrome, Parkinson disease, and acquired immune deficiency syndrome [15]. Premature activation of TGF-βs and the consequent pathological events in subchondral bone were found to contribute to the development and progression of osteoarthritis. In physiological conditions, TGF-βs in the matrix are activated and released into the interstitial space or lumens during tissue injury or remodeling. Stem cells or progenitor cells harbored in the nearby tissue are then recruited to the remodeling site with the highest TGF-β concentration [16]. In conjunction with other signals, TGF-βs further regulate whether the stem cells differentiate or self-renew. In this way, TGF-β acts as the key coupling factor during bone remodeling that directs the migration of mesenchymal stem cells (MSCs) in normal conditions [17].

Intra-articular injury alters the mechanical environment of the joint dramatically. Osteoclastic bone resorption is substantially elevated in adaptation to the new mechanical environment, which results in the release of a large quantity of active TGF-βs in the relatively confined space of subchondral bone. The normal pattern of TGF-β gradients from the bone resorption site to the bone marrow cavity is then disrupted because of the excessive liberation of TGF-β. As a result, MSCs or osteoprogenitors cluster in the bone marrow cavity or randomly deposit on bone surfaces. De novo bone formation at inappropriate times and/or locations ensues [6].

TGF-β also regulates stem cell behavior through its direct or indirect effects in modulating the bone marrow microenvironment. For example, bone formation always couples with angiogenesis and vascularization, which creates an environment rich in MSCs. TGF-β can promote angiogenesis, which provides an environment favorable to bone formation and therefore contributes to the abnormal bone formation in osteoarthritic subchondral bone. TGF-β signaling plays an important role in epithelial-mesenchymal and endothelial-mesenchymal transitions [18]. In the context of different morphogenetic events, epithelial or endothelial cells transdifferentiate into stromal lineage cells, which are involved in many pathological conditions such as fibrosis [19]. Therefore, aberrant elevated active TGF-β could be associated with formation of poorly mineralized bone and increased marrow perfusion and fibrosis in osteoarthritic subchondral bone. When active TGF-β1 is released prematurely by osteoblastic cells in the transgenic mouse, early onset of osteoarthritic-like changes in knee joints is common [6]. In these mice, the abnormally elevated TGF-β levels in subchondral bone induce abnormal bone formation and structure alteration and consequently contribute to articular cartilage degeneration [6]. The linkage of gain of function of Smad3 mutations with the early onset of hip and knee osteoarthritis in humans also supports this notion [20]. Indeed, osteoarthritis progression can be attenuated substantially in the mouse PTOA model when the TGF-β signaling pathway in MSCs is blocked genetically [6].

The Role of TGF-β in Osteoarthritic Articular Cartilage

Cartilage degeneration is another major concern in osteoarthritis. Articular cartilage has limited self-repair capability, and cartilage lesions rarely heal if the damage is larger than 3 mm in diameter [21]. The role of TGF-β in cartilage is different than its role in subchondral bone. For example, genetically deleting TβR-II or Smad3 in chondrocytes resulted in early onset of osteoarthritis in animal models, as evidenced by the hypocellularity and decreased matrix protein synthesis of chondrocytes [22]. The effects of TGF-β in stimulating chondrogenic condensation, proliferating chondroprogenitors, and inhibiting terminal differentiation of chondrocytes have been evidenced in multiple in vitro studies. These findings suggest that TGF-β is critical to maintaining articular cartilage's functional and structural integrity [23]. The abundant latent TGF-β storage (~300 ng/mL) in the extracellular matrix of cartilage provides sufficient raw material for TGF-β activation [24]. In physiological conditions, minimal amounts of active TGF-βs are needed for the maintenance of cartilage physiological function. In osteoarthritic cartilage, many mechanisms involved in the process of TGF-β activation such as MMPs or integrins are altered [25], which may lead to excessive or insufficient activation of TGF-β. Intra-articular injury likely alters the mechanical stress distribution in articular cartilage directly or indirectly through subchondral bone. Subchondral bone changes its structure constantly in response to the mechanical environment. During the period of structural fluctuation, the capacity of subchondral bone to dissipate the mechanical load is altered or impaired. Because physiological mechanical stimulation is indispensable for maintaining the function and structural integrity of articular cartilage, abnormal mechanical stress (altered intensity or frequency) can promote catabolic events and induce cartilage degeneration [26]. Although the soluble factors responsible for propagating mechanical signals into biochemical signaling are still unclear, evidence suggests an important role of TGF-β in mechanical transduction pathways in chondrocytes [27]. In addition to TGF-β activation pathways, it has been reported that shear forces can liberate active TGF-β from the sequestration of LAP in synovial fluid [28]. TβR-I-specific inhibitor eliminated the anabolic effect of shear stress in stimulating protein synthesis in the superficial zone of articular cartilage [29]. These findings indicate that abnormal biomechanical and biochemical environments alter the TGF-β activation process, and excessive or insufficient levels of TGF-β, in turn, effect the chondrocytes' survival and function.

The responsiveness of chondrocytes to TGF-β also depends on the expression levels and activity of its receptors. The canonic TGF-β signaling pathway includes the formation of the heteromeric complexes of type I and type II receptors. A sequential phosphorylation and nuclear translocation of downstream Smads ultimately triggers the expression of the target genes. Dysregulation of TGF-β signaling pathways or differential expression of TGF-β receptors in the chondrocytes has been reported in various in vivo studies, including a surgically induced PTOA animal model. TβR-II degradation and decreased TβR-I expression blunt the sensitivity of articular chondrocytes to TGF-β, contributing to cartilage degeneration [30]. The expression pattern of TβR-I in chondrocytes is markedly different in osteoarthritic cartilage. The dominant TβR-I receptor shifts from ALK5 to ALK1 [31]. TGF-β signals from these two pathways influence the metabolism of chondrocytes in an opposing fashion [32]. TGF-β acts as an anabolic factor on chondrocytes, stimulating matrix protein production when signaling through ALK5, and as a catabolic factor when ALK1 is mediating its downstream signaling [33]. In addition, there are several other factors involved in the signaling transduction pathway of TGF-β by modulating the sensitivity of receptors to the ligand or the internalization process of the receptors. For example, endoglin can facilitate the binding of TGF-β to its receptors with the preference to recruit ALK1 [34]. Therefore, elevated expression of endoglin in chondrocytes may promote the catabolic effect by making ALK1/pSmad1/5/8 the dominant signaling pathway of TGF-β. Betaglycan is a homolog of endoglin but it has distinctive functions in regulating the TGF-β pathway. Betaglycan can direct clathrin-mediated endocytosis of TβR-I and TβR-II [35] and increase the sensitivity of TβR-II to its ligands [36]. CD109 is another identified TGF-β co-receptor. It negatively regulates TGF-β signaling by promoting TGF-β receptor internalization and degradation [37]. Thus, during osteoarthritis development, the altered TGF-β signaling in articular cartilage may potentially be corrected by targeting these co-receptors or modulators.

The Role of TGF-β in the Osteoarthritic Synovial System

As avascular tissue, articular cartilage is nourished mainly by the synovial fluid that is secreted by the synovium. Therefore, articular cartilage is vulnerable to pathological changes in the synovial system. Although osteoarthritis is defined as "non-inflammatory arthritis," synovial hyperplasia, macrophage infiltration, and angiogenesis are common characteristics of osteoarthritic abnormality [38]. Histologically recognizable synovitis occurs in more than one-third of patients with symptomatic osteoarthritis. Persistent or episodic synovitis has been found to be related closely to osteoarthritic pain. The cytokines released by synovium have been recognized as being of pathological and clinical importance in the development of osteoarthritis. Notably, human and animal studies suggest that the concentration of TGF-β1 might be used as a prognostic indicator for PTOA. In a rabbit meniscectomy model, early postoperative concentrations of TGF-β1 in synovial lavage fluid were correlated positively with the severity of PTOA [39]. In patients with acute or chronic anterior cruciate ligament rupture, the levels of TGF-β in the synovial fluid were consistent with the persistence of inflammatory reactions, and their synovial fluid cytokine profiles were associated with the risk of developing PTOA [40]. TGF-β typically serves as an important immune suppressor during the process of inflammation. Knocking out TGF-β1 in mice is usually lethal because it induces severe inflammatory events. TGF-β receptors are expressed widely in immune cell types and have broad activities in immune regulation. In most immune reactions, TGF-β acts as a suppressor. Conversely, TGF-β sometimes plays a pro-inflammatory role by promoting the differentiation of TH17 lineage cells [41]. TGF-β was found to induce the differentiation from "attacking" type I macrophages toward "inflammatory molecule secreting" type II macrophages [42, 43]. This may underlie the mechanism of TGF-β in augmenting the tumor necrosis factor-α- or interleukin

(IL)-1β-induced expression of MMP3, IL-6, IL-8, and macrophage inflammation protein 1α in synoviocytes [44]. Therefore, TGF-β and its downstream signaling could potentially be therapeutic targets for osteoarthritic synovitis.

Modulation of TGF-β Activity as a Potential Therapy for Osteoarthritis

Currently, no medications have shown the disease-modifying efficacy and clinically meaningful effects needed to gain regulatory approval. In animal studies and clinical trials, controlling subchondral bone abnormality seems to mitigate the advancement of osteoarthritis. Increased osteoclast activity and bone turnover rate are known pathological characteristics of subchondral bone in osteoarthritis. For this reason, the efficacy of the common antiresorptive medicine, bisphosphonate, has been tested for treating osteoarthritis in clinical trials [45]. Though the results in humans have not been as encouraging as those in animal osteoarthritis models, some drugs within the bisphosphonate class have shown beneficial effects in human studies. It is conceivable that the level of active TGF-β released from bone matrix will decrease substantially when osteoclast bone resorption is inhibited by bisphosphonate. Aberrantly activated TGF-β signaling induces abnormal bone formation in subchondral bone and contributes to osteoarthritis progression. This at least partially explains the efficacy of bisphosphonates in treating osteoarthritis. TGF-β-neutralizing antibodies or TβR inhibitors may achieve a high specificity in suppressing TGF-β signaling in subchondral bone, and their ability to attenuate degeneration of articular cartilage was observed in anterior cruciate ligament transection osteoarthritis rodent models [6]. However, as a critical growth factor, TGF-β has a broad spectrum of functional activities such as growth inhibition, cell migration, cell invasion, epithelial-mesenchymal transition, and immune regulation. The role of TGF-β in maintaining the homeostasis of articular cartilage is different than that of subchondral bone. Thus, systemic administration of a TβR-I inhibitor might disrupt tissue homeostasis of other organs, resulting in unwanted adverse effects and chemical toxicity. Novel approaches that inhibit TGF-β signaling, specifically in subchondral bone, may reduce potential adverse effects while maintaining the therapeutic efficacy of the TβR-I inhibitor.

The function and behavior of cells are not only cell-context-dependent but are also regulated by the local microenvironment. Aberrant elevation of TGF-β is one of the primary factors in the microenvironment that drives the sequence of pathological changes in osteoarthritic subchondral bone such as clustering of osteoprogenitors, de novo bone formation, and neovascularization in marrow cavities. Many other growth factors or cytokines such as Wnts, bone morphogenetic protein (BMP), and insulin-like growth factor are also reported to be involved in the development of subchondral bone abnormality [46]. Parathyroid hormone (PTH) plays an important role in bone metabolism and calcium homeostasis. Recently, PTH was found to orchestrate the signaling of local factors and thereby improve the microenvironment in bone marrow [47]. TβR-II can form a complex with PTH type I receptor (PTH1R). The binding of PTH with PTH1R downregulates TGF-β signaling by inducing internalization of the TβR-II/PTH1R complex [47]. It is known that BMP and Wnt signaling can promote the commitment of MSCs to osteoblastic lineage cells [48]. PTH upregulates BMP and Wnt signaling and, therefore, positively regulates osteogenesis. Additionally, angiogenesis is always coupled with osteogenesis during bone formation. PTH has been shown to reduce the distance between newly formed vessels and sites of bone formation [49]. Therefore, by coordinating the effects of these osteogenic factors, PTH may alleviate abnormal bone formation while stimulating normal bone turnover at the right location. Moreover, PTH is a well-recognized anabolic factor during cartilage development and maintenance [50]. PTH may be developed as a therapeutic agent because of its potential ability to rescue pathological changes in both osteoarthritic cartilage and subchondral bone.

Summary

The diarthrodial joint works as a functional unit, and osteoarthritis affects almost all of its structural components. TGF-β is a crucial factor that regulates the physiological turnover of subchondral bone and articular cartilage. Dysregulation of TGF-β1 signaling leads to failure in maintenance of joint homeostasis during the development and progression of osteoarthritis. Because the effects of TGF-β may differ according to tissue type within the joint and may vary at different time points, differential and tissue-specific treatments targeting TGF-β signaling may produce optimal therapeutic effects.

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Chapter 2
Imaging Modalities for Post-traumatic Arthritis

Filippo Del Grande, Luca Deabate, and Christian Candrian

Key Points
- Magnetic field strength increases the signal to noise ratio (SNR) and can influence cartilage detection and grading.
- T2 mapping, dGEMERIC, T1 rho, and Sodium imaging are advanced MRI techniques that allow the biochemical evaluation of the cartilage.
- Bone marrow edema (also called bone marrow lesions) is commonly present in patients with OA mainly in areas of mechanical loading.

Introduction

Osteoarthritis (OA) is a rapidly increasing condition in US population ranging from 21 million in 1995 to 27 million in 2007 [1]. Aging population, male gender, increasing overweight, and genetic predisposition are the main general risk factors for the disease [2]. Besides these general risk factors, other local biomechanical conditions such as post-traumatic joint instability and/or misalignment are responsible for OA [2]. It is estimated that post-traumatic etiology accounts for approximately 12% of OA of lower extremities [3].

The well-known imaging findings of primary OA such as subchondral bone sclerosis, osteophytes, joint space narrowing, and subchondral cysts are similar to

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_2

post-traumatic OA [3]. Conventional radiography, CT imaging, and MR imaging are currently the imaging modality available in the clinical practice to assess OA. The main difference between post-traumatic OA and idiopathic OA is the joint location. Ankle joint, shoulder joint, and elbow joint are generally atypical locations for primary OA but are involved in post-traumatic OA (Figs. 2.1 and 2.2). For instance, less than 2% of hip OA are post-traumatic, whereas approximately 80% of ankle OA are post-traumatic [3].

The purpose of our chapter is to familiarize oneself with the most common imaging modalities used in clinical practice to assess post-traumatic OA, i.e., conventional radiography and MR imaging, and to review the diagnostic performance, the reliability, and the correlation of imaging findings with pain. Owing to the scarcity of the literature on imaging in post-traumatic OA, our chapter will review the general principles of imaging of OA and will focus on post-traumatic OA when possible.

Conventional Radiography

Conventional radiography (CR) is the least expensive and most widely available imaging modality to assess OA in the clinical practice. CR allows not only to detect morphological changes of OA but also to follow the disease progression by measuring the joint space narrowing (JSN) (Fig. 2.3) [4, 5]. Slowing of the JSN progression is the official criterion approved by the Federal and Drug Administration (FDA) to demonstrate efficacy of drugs in phase III trials of OA [4, 5].

JSN is a complex process that involves several anatomical structures depending on the joint. For instance, in the knee joint, cartilage loss, meniscal degeneration, and/or meniscal extrusion are involved in the joint space narrowing process [6].

In the clinical practice, radiologists don't use scoring systems to report OA. Kellgren and Lawrence (K-L) is the best-known semiquantitative grading system to assess OA and was originally developed for anteroposterior knee radiographies [7]. The 5-point K-L scoring system stratifies OA according to four conventional radiology findings: presence of bony osteophytes, joint space narrowing, presence and degree of subchondral sclerosis, and bony deformity (Fig. 2.4) [7, 8]. K-L grade 0 indicates none OA, K-L grade 1 indicates doubtful OA, K-L grade 2 indicates minimal OA, K-L grade 3 indicates moderate OA, and K-L grade 4 indicates severe OA. Although the K-L scoring system could help to increase communication between radiologists and clinicians, it shows some important limitations that prevent its introduction in clinical practice and in research protocols. One of the major limitations of K-L grading system is the grouping of the majorities of patients in the grade of moderate OA (grade 3) [4]. Furthermore, K-L method shows high interpretation variability with poor to moderate inter-observer agreement [9]. Experience and training seems to play an important role for reliability reporting. Differences arise between readers on site and an expert centralized reader as well, which highlight the importance to use a centralized reader in the research projects [10].

Fig. 2.1 (**a**) Anteroposterior and (**b**) lateral conventional radiographies and (**c**) coronal and (**d**) sagittal CT MPR reconstruction of the elbow of a 60-year-old patient after internal fixation of a radial head fracture. The patient developed post-traumatic OA of the elbow which is an atypical location for primary OA. Radiographs and CT show humero-ulnar and humero-radial OA. The osteophyte arising from the olecranon ulnae causes extension deficit

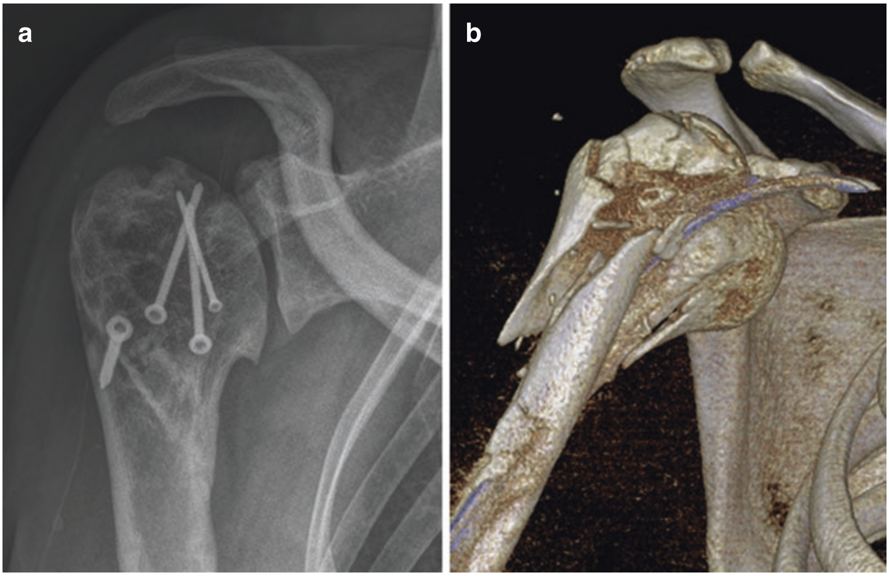

Fig. 2.2 (**a**) Anteroposterior shoulder view and (**b**) 3D reconstruction of the shoulder of a 25-year-old patient. The 3D reconstruction (**b**) shows a displaced comminuted humerus fracture after MVA. Two years later the patient developed a post-traumatic OA (**a**)

The major drawbacks of CR are lack of sensitivity [8, 11] and of reliability [9]. In clinical practice, standard anteroposterior and lateral views are generally sufficient; additional views are rarely requested. The role of additional special projection on knee MRI is debatable in the literature. In patients with arthroscopy-confirmed grade II femorotibial chondromalacia, the 45°flexion PA and the standing AP view are both insensitive to detect OA [11]. However, a more recent systematic review concluded that the 45°flexion PA view was more sensitive than the standing AP view for the detection of femorotibial OA, especially in patients suffering from advanced OA [8]. The two studies showed contradictory results, probably because of the relatively young population (average 38 years old) and the mild femorotibial OA in the first study compared to the meta-analysis.

To the best of our knowledge, to date, only two studies focus on the reliability of imaging of post-traumatic OA [12, 13]. K-L scoring system is reliable and correlates with clinical symptoms in patients with ankle OA several years after open reduction internal fixation of a malleolar fracture. Furthermore, adding the talar tilt angle (modified K-L scale) will result in even better differentiation of clinical outcomes [13].

In order to assess the reliability of grading systems for post-traumatic ankle OA, Cleassen and colleagues analyzed three different methods: the Van Dick, the Takakura, and the K-L methods. A total of 118 orthopedic surgeons and residents graded 128 ankle radiographs after bi- or trimalleolar ankle fractures. The authors

Fig. 2.3 Anteroposterior conventional radiography of medial OA of the knee with osteophytes, subchondral sclerosis, and joint space narrowing

found only fair inter-reader agreement for the Van Dick and low for the Takakura and K-L classification systems. According to the results of the study, the authors warned to use these classifications in the clinical practice [12].

MR Imaging

MRI has a high soft tissue contrast that allows to visualize the whole joint, i.e., the bone, the synovia, the ligaments, the capsule, and mainly the cartilage [5, 14, 15]. Furthermore MRIs allow to assess the morphology and the composition of the cartilage [16].

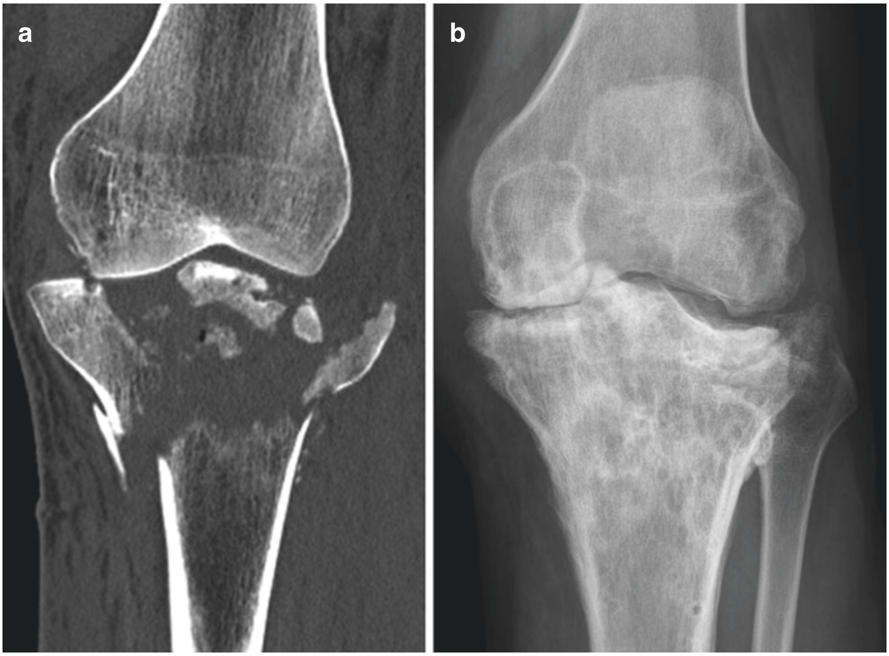

Fig. 2.4 (**a**) Coronal MPR CT reconstruction of the knee of a comminuted displaced fracture of the proximal tibia of a 36-year-old male patient after MVA. (**b**) Anteroposterior conventional radiography 6 years later shows severe medial knee OA (K-L 4)

Studies on morphological cartilage assessment show a large heterogeneity of results depending on several technical factors. A wide range of sensitivity from 0% to 86% is reported for the detection of early cartilage lesions and from 47 to 98% for the detection of more advanced cartilage lesions [17].

Among the several technical factors, higher magnetic field strength increases the signal-to-noise ratio (SNR) and can influence cartilage detection and grading. Masi and colleagues demonstrated higher accuracy in cartilage lesion detection and higher ability to grade cartilage lesions on porcine model on 3 tesla compared to 1.5 tesla MRI [18]. Kijowski et al. compared the detection of cartilage lesion of the knee on 3 tesla MRI compared to 1.5 tesla MRI with arthroscopy in two different study populations. The authors concluded that 3 tesla MRIs show higher specificity and higher accuracy but not higher sensitivity compared to 1.5 tesla MRI [19]. Wong et al. found a modest but significant increase in sensitivity and accuracy of diagnostic lesions on 3 tesla MRI compared to 1.5 tesla MRI. Additionally the authors found a higher grading and higher confidence in grading cartilage lesions [20].

T2 mapping, dGEMRIC, T1 rho, and sodium imaging are advanced MRI techniques that allow the biochemical evaluation of the cartilage [16]. A detailed description of compositional MRI techniques for cartilage evaluation will go far beyond the scope of this chapter. It is only worthy to mention that these compositional techniques are rarely used in clinical practice mainly because of long acquisition time and the need to use special pulse sequences and/or dedicated hardware [16].

Association Between Pain and Imaging Findings of OA

Association between pain and imaging findings in OA is one of the greatest challenges for researchers, radiologists, and referring physicians. Hyaline cartilage is avascular and aneural and as such cannot be the source of pain [21]. Pain transmission is probably the result of more complex and indirect mechanisms involving other articular structures [21]. It is speculated that pain could be secondary to the exposure of nociceptors of the subchondral bone, to the increased intraosseous pressure secondary to vascular congestion, and/or to cartilage damage that can lead to synovitis [21].

Prevalence studies on hip OA show only low correlation between imaging findings and pain. In the Framingham OA study, a community-based prevalence study in which symptomatic and asymptomatic subjects underwent hip radiographies, nearly one out of five subjects shows CR features of hip OA, but less than 5% were symptomatic [22].

Another population-based observational study emphasizes the low sensitivity of CR for OA and the low correlation of MRI findings of OA with pain [23]. In the study, a cohort of 710 patients without evidence of knee OA (K-L grade 0) underwent MRI of the knee. The authors assessed the prevalence of MRI finding suggestive for OA such as osteophytes, cartilage damage, bone marrow lesions, synovitis, subchondral cysts, meniscal lesions, and bone attrition. Some interesting clinical considerations came out from the study. First, 89% of subjects showed MRI features compatible with OA. Second, a high prevalence of symptomatic (97%) and asymptomatic (88%) subjects showed at least one MRI feature of OA. According to the study, MRI features of OA are so common in asymptomatic subjects that should not be used as a diagnostic tool for OA. The role of MRI will be rather to rule out other pathologies that can mimic OA such as subchondral bone fractures, osteonecrosis, and insufficiency fractures [23].

Although the correlation between pain and imaging finding is low, some imaging findings such as bone marrow edema, synovitis/effusion, and bone attrition are predictive of pain in patients with OA.

Bone marrow edema (also called bone marrow lesions) is commonly present in patients with OA mainly in areas of mechanical loading (Fig. 2.5) [24]. Bone marrow edema is considered a strong pain generator in patients with OA [25–27] and predictive for OA progression [24]. Interestingly, the fluctuation of bone marrow edema on MRI correlates with pain fluctuation [28]. Histologically, bone marrow edema in patients with OA is a mixture of fibrosis, hemorrhage, trabecular fractures,

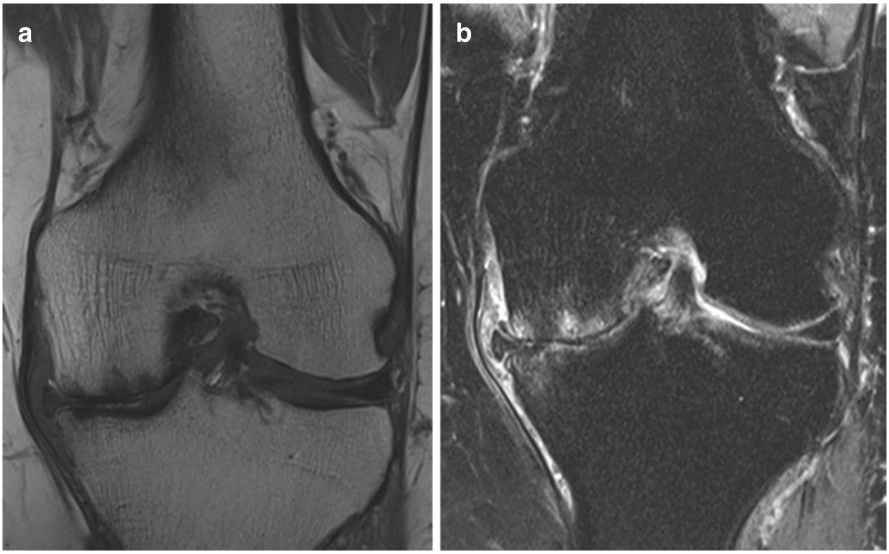

Fig. 2.5 (**a**) Coronal T1-weighted sequences and (**b**) T2-weighted sequences of a 71-year-old female patient with painful OA. Note the osteophytes arising from the medial compartment of the knee, the meniscus subluxation, and diffuse cartilage loss. T2-weighted sequences show the bone marrow edema of medial condyle and the medial tibial plateau

and only a minor component of edema [29, 30]. Bone attrition is a common bony feature in OA and plays an important role in association with bone marrow edema to generate pain [27]. Lastly, several studies emphasize the association of synovitis/joint effusion with knee pain [26, 27, 31, 32].

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Chapter 3
Economic Implications of Post-traumatic Arthritis of the Hip and Knee

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Key Points

- To understand how patient demographics, injury patterns, and the management of hip and knee PTOA contribute to the disease burden
- To assess the direct and indirect economic burden associated with PTOA of the hip and knee

Introduction

There are 27 million [1] people in the United States who have been diagnosed with degenerative joint disease (DJD). Patients with osteoarthritis (OA) frequently present with joint stiffness, pain, or instability due to degeneration of the articular surface. In the event OA develops after an acute injury, this subcategory of OA is referred to as post-traumatic osteoarthritis (PTOA). Posttraumatic osteoarthritis of

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_3

the lower extremity comprises about 12% of OA overall, of which PTOA of the hip and knee account for 0.5% and 6.3%, respectively [2].

Following the initial injury, there are two mechanisms by which OA may ultimately develop. One pathway is through damage to the articular surface of the joint at the time of injury followed by subsequent, chronic degeneration of the joint secondary to a continuous inflammatory response [3]. Another pathway is through chronic inflammation to the articular surface caused by joint instability or incongruity following an inadequately treated joint injury. The pathophysiologic mechanism in PTOA and primary OA is similar; however, PTOA is initiated by an acute traumatic episode [4].

Given the association between PTOA and acute injury, the patient population that typically develops PTOA is younger and more active than patients diagnosed with primary OA [5]. Patients with a history of lower-extremity joint trauma will on average develop OA 10 years sooner than those without a history of trauma [6]. Despite extensive research aimed at better managing PTOA, over 40% of patients with significant soft tissue injuries to the knee will develop symptomatic OA [3].

An abundant amount of resources have been dedicated to understanding the management of OA. The Agency for Healthcare Research and Quality (AHRQ) ranked OA as one of the top 5 most costly conditions in the United States [7]. Yet, there is a paucity of literature evaluating the economic effects of secondary causes of OA including PTOA. This is particularly concerning as recent studies have demonstrated that the direct costs associated with managing PTOA are substantially greater than those diagnosed with primary OA [8]. Additionally, as a growing number of individuals participate in high-risk activities, the incidence of PTOA is expected to increase. Given this growing trend, PTOA poses a substantial financial burden on the healthcare system. Thus, the aim of this review is to shed light on the clinical and economic implications of PTOA. Emphasis will be placed on the direct, indirect, and long-term costs associated with PTOA. Finally, we will present potential solutions which may improve the delivery of care and reduce the financial burden on all stakeholders.

Post-traumatic Osteoarthritis of the Knee

Post-traumatic osteoarthritis of the knee is responsible for 6.3% of the overall prevalence of OA [2]. Patients diagnosed with PTOA are on average 10 years younger, and more active than those with primary OA [2], and have a five times greater likelihood of developing PTOA with a past history significant for knee injury [9]. Specifically, the incidence of ligamentous and meniscal injury is associated with a 50% incidence of knee PTOA within 10–20 years [10]. Given the rapidly progressive nature of PTOA and the young active population often affected by this disease process, it is not uncommon to see debilitating manifestations of the disease within the third and fourth decades of life.

Types of Injuries Associated with PTOA of the Knee

Anterior Cruciate Ligament Injuries

Anterior cruciate ligament (ACL) pathology is commonly associated with PTOA and is responsible for a quarter of knee injuries subsequently resulting in degenerative changes of the knee [11]. Investigators have reported that 13% to 39% of patients with isolated ACL injuries and 21% to 48% of individuals with complex ligamentous injuries will develop symptomatic PTOA within 10 years of injury [12, 13]. Based on the severity of the injury, cartilage damage after ACL and meniscus injuries can develop into PTOA regardless of whether the ligaments or meniscus is repaired. Even in those who have their ACL reconstructed, about 50% of patients go on to develop OA within 14 years (Fig. 3.1) [14].

Meniscus Injuries

Meniscal injuries are another common cause of degenerative knee changes and are responsible for 23% of patients with PTOA [11]. Swenson et al. [15] observed that following meniscal injury, the first signs of OA were identified 10 years after injury

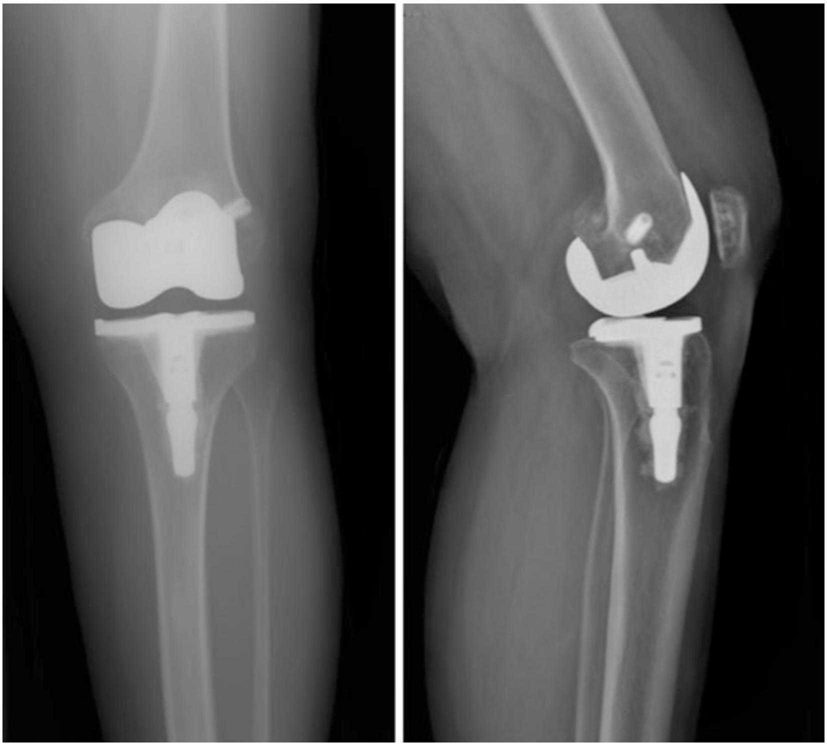

Fig. 3.1 Patient with ACL reconstruction that went on to total knee arthroplasty

at an average age of 50 years. The investigators also reported that the age of the patient at the time of the injury played a role in the timing of the onset of OA as patients who had an isolated meniscal injury between the ages of 17 and 30 developed radiologic OA after 15 years, whereas patients over the age of 30 years developed degenerative changes within 5 years [15]. A study by Badlani et al. [16] compared the characteristics of meniscal injury in those who did and did not develop PTOA within 2 years of injury. The authors reported that complex tears, extrusion of the meniscus, tears greater than one-third of the radial width of the meniscus, and injuries longer than one-third of the longitudinal length of the meniscus occurred more frequently in those who developed PTOA.

Intra-articular Fractures

Patients with fractures of the articular surface are at increased risk for developing PTOA (Fig. 3.3). Studies have demonstrated that up to 31% of these patients will develop PTOA of the knee depending on the location of the fracture [17]. In a study by Honkone [18], 44% of patients with a previous history of tibial plateau fractures developed arthritis within 7.6 years of surgery. Although Honkone and colleagues demonstrated the high prevalence of arthritis within patients with history of tibial plateau fractures, the mechanism and severity of injury is often the best prognostic indicator of PTOA. Higher load injuries are more likely to be associated with immediate damage to the surrounding cartilaginous structures, whereas joints may be more forgiving to less severe injuries [19, 20].

Management of Post-traumatic Osteoarthritis of the Knee

Primary Prevention

Primary prevention strategies are implemented in order to prevent the initial injury from occurring and are considered to be the most effective management tool for prevention of PTOA. Specifically for ACL rupture prevention, neuromuscular training, aerobic conditioning, resistance training, and plyometrics have all been shown to strengthen soft tissue around the knee, reducing the incidence of ligamentous injury [21]. Recent literature has reported a 70% risk reduction in ACL ruptures when proper exercise regimens are practiced [22]. The costs associated with primary prevention of PTOA are not unreasonable. Exercise programs using these preventative therapies have been estimated to cost between $50 and 400 USD per session and may require a 3-hour commitment per week. Given the high costs associated with ACL reconstruction ($38,121 to $88,538 USD) [23], primary prevention is particularly worthwhile among high-risk patients.

Secondary Prevention

Secondary preventative measures are indicated in individuals who have already sustained a joint injury. The goal of secondary prevention is to prevent worsening of a joint injury. Although surgical techniques and knowledge surrounding the restoration of joint stability and articular surface congruity have improved over the past 25 years, up to 50% of individuals sustaining a serious joint injury warranting surgical intervention will go on to develop OA [24]. While in the majority of patients, arthroscopic repair of soft tissue, ACL reconstruction, and partial meniscectomy are the current standard of care, the literature has not demonstrated a reduced incidence of PTOA with these interventions (Fig. 3.1) [25].

Similarly, the benefits are unclear in patients undergoing autologous chondrocyte implantation (ACI), microfracture, and chondroplasty. Knutsen et al. assessed 5- [26] and 15-year [27] outcomes following ACI and microfracture repair in symptomatic patients with cartilage defects and reported a failure rate as high as 43% and 33% for the respective procedures. In addition, the study also demonstrated that OA develops in 33% of patients undergoing ACI and microfracture repair at 5 years and greater than 50% of patients at 15 years. Given the similar long-term outlook, it is important for providers and patients to be aware of the direct and indirect costs associated with the various treatment modalities as there may be substantial differences between them.

Tertiary Prevention

When primary and secondary prevention measures have failed and PTOA has developed, alternative treatment modalities may be implemented to slow the progression of OA. In younger, more active individuals, the clinician is left with the difficult task of developing a treatment strategy aimed at minimizing pain, improving function, and delaying TKA. Such an approach requires a host of patient-centered strategies focusing on tiered interventions. The least invasive therapies should always be implemented first regardless of the patient's age. These interventions include weight loss, orthotics, knee bracing, and physical therapy. Physical exercise has been shown to provide pain relief, particularly when combined with strengthening and aerobic activities. Various pharmacological treatments commonly used in combination with first-line therapies include oral analgesic agents and intra-articular hyaluronic acid or corticosteroid injections. Although nonsurgical interventions have been shown to provide temporary relief, they do not have any impact on the reversal of the underlying joint disease.

If nonsurgical management is unsuccessful, there are multiple surgical alternatives available. Total knee arthroplasty (TKA) has been shown to alleviate knee pain and improve knee function (Fig. 3.1). Although very effective, TKA in patients with PTOA may be challenging due to anatomic malalignment, bony deficiency, joint instability, contractures, compromised soft tissue, and retained hardware [28, 29]. These obstacles contribute to high complication rates, increased length of hospital stay, readmissions, and worse functional outcomes than patients preoperatively diagnosed with primary OA [8, 30].

Another method of surgical management particularly among younger patients with significant deformities are osteotomies. These procedures are typically done in younger (<50 years) more active patients with obvious bony malalignment. Although an osteotomy has been shown to be associated with delaying the need for TKA and improved pain and function scores [31], the benefits of surgery gradually deteriorate as the disease progresses. Long-term studies have demonstrated 10-year failure rates of 24.6% [32].

For patients with localized cartilaginous defects, osteochondral grafts may be indicated. The procedure is almost exclusively conducted in younger patients and has been associated with variable outcomes. A systematic review after a mean follow-up of 58 months demonstrated an overall failure rate of 18%, while 65% of patients had little to no radiographic change in knee arthritis on follow-up [33].

In order to deliver the highest quality of care, healthcare providers must emphasize primary and secondary prevention. Tertiary prevention will frequently require costly surgical procedures which may resolve the underlying joint pathology but often with suboptimal outcomes. Thus, healthcare providers should continue to investigate the pathophysiological association between mechanical injury and the subsequent degenerative changes observed in the joint. Moreover, structured treatment protocols are needed for the management of PTOA as these patients frequently require multiple surgical interventions during their lifetime, each associated with an independent list of complications and expenditures.

Post-traumatic Osteoarthritis of the Hip

Although PTOA of the hip is substantially less common than PTOA of the knee [2], its clinical and economic implications must also be considered. Unlike in the knee, time between injury and the development of PTOA of the hip is slightly lengthier, and the population that is affected is generally older. One population-based study demonstrated that in patients who developed hip PTOA following a traumatic event to the hip, the median age at which symptoms occurred was 66 years, approximately 13 years following the injury [34]. Furthermore, the study reported that injuries to the hip have been associated with a 4.3-fold increase in the risk of hip osteoarthritis. Although there are numerous mechanisms leading to PTOA of the hip, common causes include articular incongruity and disruption of the articular surface most frequently due to fractures or hip dislocations.

Types of Injuries Associated with PTOA of the Hip

Hip/Acetabular Fractures

Hip fractures may predispose patients to secondary arthritis of the hip, mainly as a result of failed subcapital hip fixation, and to a lesser extent intertrochanteric and subtrochanteric fractures. The specific mechanisms that lead to PTOA include high-energy fracture patterns, injury to the articular surface, and nonunions following injury. In addition, avascular necrosis resulting from traumatic devascularization or hardware placement following fracture fixation may subsequently cause PTOA of the hip (Fig. 3.2) [35].

Although acetabular fractures of the hip are rare compared to other types of fractures in the hip region, up to a quarter of these patients will go on to develop PTOA [36]. Acetabular fractures have a bimodal distribution occurring in the elderly and young males. The mechanism of injury in these two populations varies significantly. Elderly patients are more likely to sustain acetabular fractures following low-energy falls, whereas younger individuals typically sustain a high-energy injury [37]. Unfortunately, acetabular fractures predominantly occur in the elderly population, and their incidence has increased substantially in the past quarter century as the geriatric population continues to be the fastest growing subgroup in the United States [38] (Fig. 3.3).

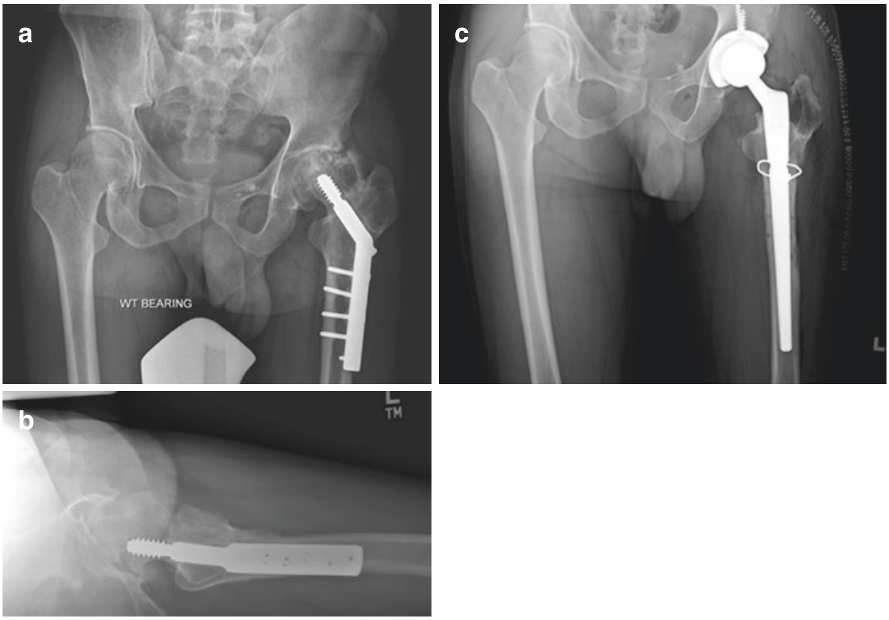

Fig. 3.2 AP (**a**) and lateral (**b**) view of previous intertrochanteric hip fracture treated with a sliding hip screw construct that went on to avascular necrosis. AP pelvis after removal of the sliding hip screw and left total hip arthroplasty treated with a modular diaphyseal engaging stem (**c**)

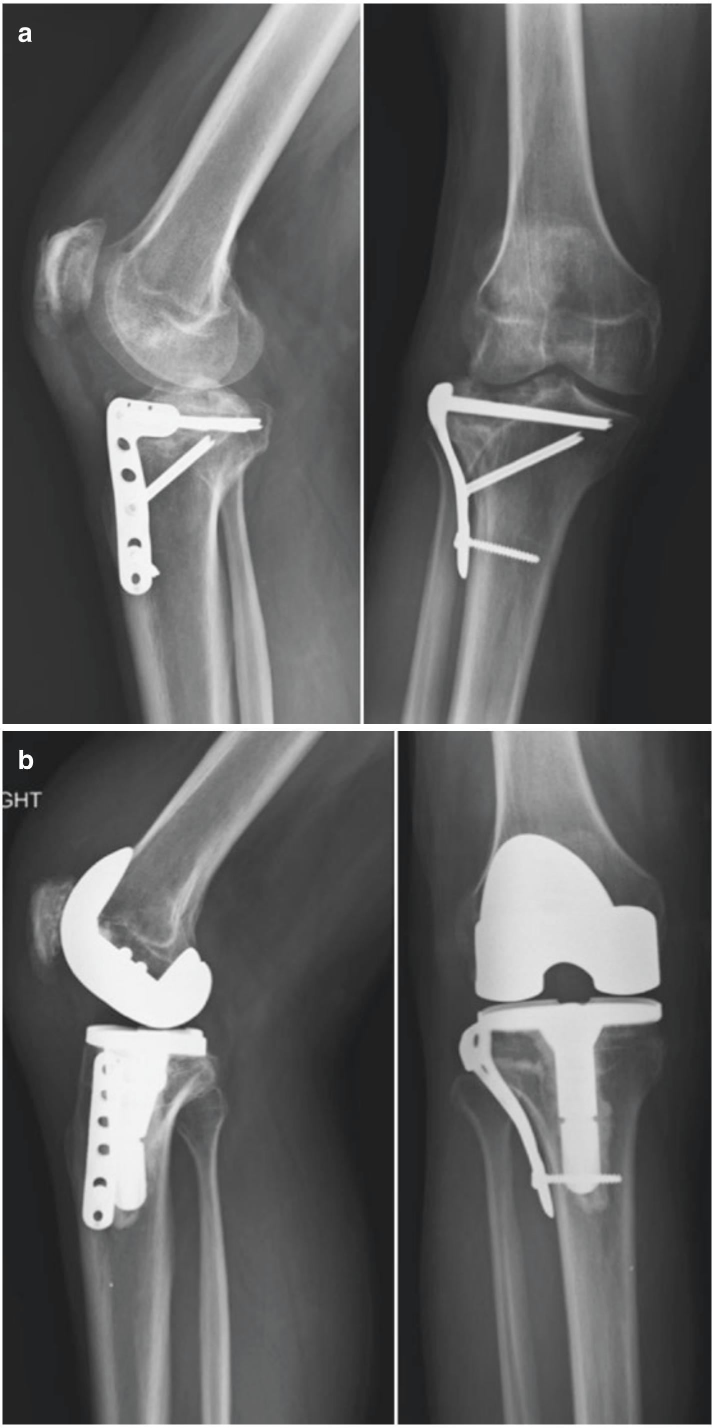

Fig. 3.3 Tibial plateau fracture (**a**) that went on to total knee arthroplasty (**b**). Clinical picture of the complex skin incision associated with reconstruction (**c**)

Fig. 3.3 (continued)

Hip Dislocations and Osteonecrosis

Posterior hip dislocations represent about 90% of all traumatic hip dislocations [39], and almost all injuries are a result of motor vehicle collisions. Given the strong association between these two events, young males (16–40 years) are most likely to be affected [40]. Hip dislocations lead to PTOA due to joint incongruity and instability, resulting in chronic inflammation and damage to the articular surface of the hip. In addition, hip dislocations may also result in acetabular fractures and osteonecrosis of the hip head. The overall occurrence rate of PTOA in the hip following posterior hip dislocations ranges from 19% to 55%, with a direct correlation between dislocation severity and the likelihood for future PTOA [41].

Management of PTOA in the Hip

Primary Prevention

Given the nature of the injury mechanism responsible for the majority of hip PTOA, preventing injury to the hip is somewhat more difficult than the knee. Broad measures have been shown to prevent acetabular fractures and hip dislocations which include safe driving practices and stringent adherence to fall precautions in the elderly. If fall precautions are in place, the cause should be investigated by a healthcare provider, medications should be reviewed, strength and balance exercises implemented, and regular vision checkups obtained. Finally, various medical conditions can predispose patients to osteonecrosis and, subsequently, PTOA of the hip. Thus, these high-risk patients may benefit from physician-directed preventative measures.

Secondary Prevention

Once a hip injury has occurred, a number of secondary measures can be implemented in an effort to prevent progression to PTOA. After an acetabular fracture, sufficient anatomic reduction is essential to ensure the joint has the best chance of survival. It should be emphasized that achieving anatomic reduction does not rule out the occurrence of PTOA [42, 43]. When managing hip dislocations, prompt reduction has been correlated with improved outcomes and reduced risk of complications such as the development of avascular necrosis of the femoral head. The orthopedic literature supports hip reduction as soon as possible or within 12 hours following the injury [41].

Tertiary Prevention

Once primary and secondary preventative measures have been exhausted, total hip arthroplasty (THA) may ultimately be indicated. Initially, many of the same nonsurgical management strategies of PTOA of the knee are shared with management of the hip. Once progression of PTOA of the hip can no longer be adequately managed nonoperatively, more invasive interventions including THA may be required (Fig. 3.2). Patients receiving these interventions are usually younger than those receiving THA secondary to primary OA. Although the risk for revision surgery is higher in younger patients, implant durability has improved substantially over the last three decades making THA in younger patients feasible. Despite the improvements, THA in the setting of PTOA has been linked with worse peri- and postoperative outcomes [44]. Thus, the possibility for longer operative times, higher rates of complications, early failures, and revision THA should be discussed with the patient. In rare circumstances, when the arthritic disease in the hip joint is so severe and previous attempts of THA have failed, rarely hip arthrodesis or resection arthroplasty may be indicated. Studies have demonstrated that although patients may be functionally limited, these can be effective procedures for the management of pain. However, arthrodesis has been associated with new onset ipsilateral knee and lower back pain due to the straining forces being placed on the proximal and distal joints. Other concerns associated with arthrodesis include highly variable union rates, likelihood of returning to work, and satisfaction rates, all of which should be discussed at length prior to surgery [45].

Costs Associated with Post-traumatic Osteoarthritis

There has been a robust effort to investigate the economic implications of primary OA and methods of better managing it while minimizing costs. However, the lack of large-scale epidemiologic studies evaluating the prevalence of PTOA has proven to be a major barrier in the development of accurate economic models assessing the financial fingerprint of PTOA on the US healthcare system. Although these two diagnoses share many similarities, PTOA affects a younger more active population, frequently requiring multiple surgical interventions. Thus, it should not be surprising that patients with PTOA have higher direct and indirect medical costs. Moreover, many of these patients are uninsured further complicating management of this debilitating disease. While it is well recognized that OA is one of the leading causes of disability among all diseases, the costs associated with the management of OA are difficult to approximate due to the debilitating nature of the disease and the many modalities of treatment. A recent report by Kotlarz and colleagues [46] utilized data from the Medical Expenditure Panel Survey (MEPS) and estimated that OA costs the US healthcare system $185.5 billion USD annually, of which $149.4 billion USD was expensed to insurers [46]. The report also found that women accounted for nearly two-thirds ($118 billion USD) of the dollars spent on managing OA, further demonstrating the gender discrepancies existing among those diagnosed with OA.

Although the literature surrounding the economic implications of PTOA is limited, a few recent studies have helped provide some perspective on the magnitude of the associated direct costs. Brown and colleagues [2] were the first to utilize a state-based model to estimate the prevalence and disease burden associated with PTOA at a national level. The investigators demonstrated that 6.8% of all patients with OA are due to PTOA of the hip and knee, 0.5% and 6.3%, respectively. Given these reported prevalence rates, the total direct costs associated with PTOA of the hip and knee can be measured at roughly $900 million and $11.7 billion annually (Fig. 3.4). In a separate study by Chin et al. [47], cohorts of patients undergoing primary THA were compared to conversion THA, a common salvage procedure of failed hip fracture fixation secondary to PTOA. The conversion procedures were associated with a significant increase of 26% in total hospital costs over primary OA treatment which, notably, did not account for the commonly occurring postoperative complications and revision procedures following discharge. Despite the paucity of literature comparatively examining postoperative outcomes and resource expenditures associated with PTOA, the available evidence clearly suggests an increased disease burden in patients diagnosed with PTOA compared with primary OA.

The indirect disease burden associated with PTOA is somewhat more concerning, as indirect costs associated with PTOA may be three times greater than direct costs [48]. Given that this population is younger and more active and frequently requires multiple surgical interventions (i.e., ACLR, arthroscopy, fracture fixation,

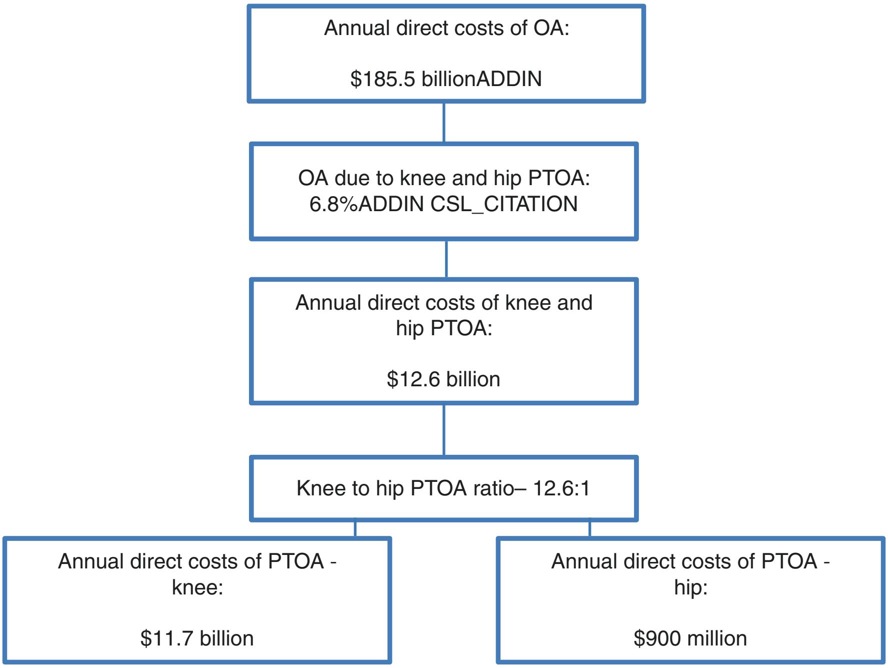

Fig. 3.4 Total direct cost of PTOA of the knee and hip

TJA) dispersed over their lifetime, the burden of PTOA economically and in terms of the individual's quality of life is substantially greater than primary OA. Additionally, many individuals with PTOA are of prime working age with higher rates of absenteeism, and overall work impairment compared with older age groups, [49] and are frequently forced to apply for disability benefits at each treatment juncture. Thus, although difficult to calculate the job-related loss of economic activity due to injuries, indirect costs of PTOA of the hip and knee together may be responsible for more than $35.3 billion annually, far exceeding the direct cost associated with PTOA (Fig. 3.5).

Recommendations

Individuals diagnosed with posttraumatic and primary OA often present with similar symptoms; however, the mechanism of injury varies significantly. Patients with PTOA have had an acute injury subsequently resulting in degenerative changes of the joint, whereas individuals with primary OA have nonspecific wear and inflammation leading to cartilage loss. Given the different mechanisms of injury and goals of treatment, it is crucial that healthcare providers manage PTOA through a

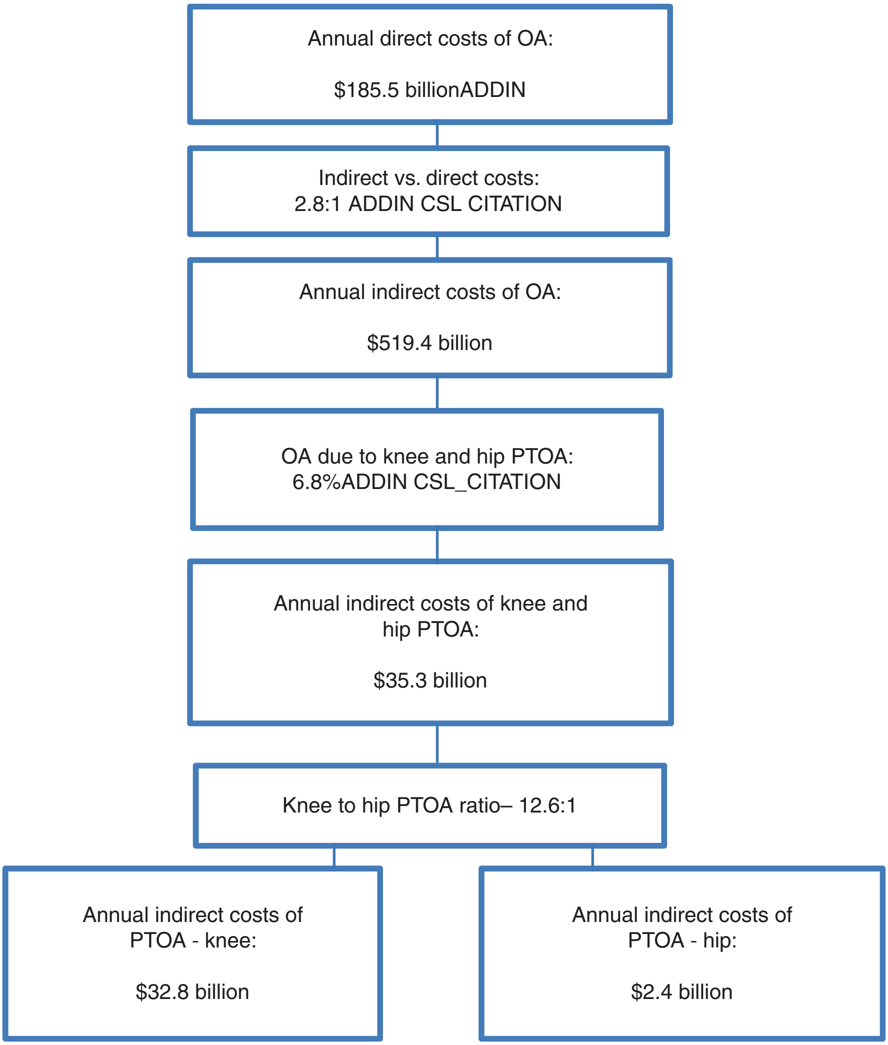

Fig. 3.5 Total indirect cost of PTOA of the knee and hip

designated care pathway (ICP) with the aim of delivering high-quality care while minimizing resource expenditures.

Our review demonstrates the paucity of literature examining postoperative outcomes and resource expenditures associated with the management of PTOA. This is at least in part due to the coding limitations associated with the *International Classification for Disease 9th Edition (ICD-9)*, which fails to differentiate between primary and secondary OA. Fortunately, as of October 2015, the *ICD-10* has been successfully implemented enabling clinicians to diagnose indications for surgery with greater specificity. If the *ICD-10* codes are properly implemented, future investigators may link clinical and billing information to better elucidate resource utilization trends among individuals with OA. However, the utilization of *ICD-10* codes alone is not sufficient as several issues still remain if these diagnostic codes are to be used to estimate the prevalence and economic burdens associated with complex disease processes such as PTOA.

First, the *ICD-10* coding system utilizes nearly 70,000 unique diagnostic codes. It is therefore essential that healthcare providers be familiar with the diagnostic codes within the scope of their practice. Healthcare providers must also avoid "gaming the system" by intentionally using a handful of nonspecific diagnostic codes. To insure that healthcare providers are meaningfully using diagnostic codes, providers should have the opportunity to participate in courses designed to better define the strengths and limitations of the *ICD-10* coding system. Additionally, as mandated by the Affordable Care Act (ACA), healthcare organizations and their providers are responsible for accurately documenting and reporting clinical metrics. Failure to properly do so will likely result in penalties and withheld payments. Thus, we suggest that healthcare organizations periodically audit the diagnostic codes being assigned to episodes of care, improving institution-wide compliance, while also strengthening the quality of the data collected.

Lastly, it is crucial that ICD-10 codes be aligned with CPT and Medicare Severity Diagnosis-Related Groups (MS-DRGs) in order to differentiate arthroplasty procedures by preoperative indication. Disease-specific procedure codes similar to those used in conversion THA and revision arthroplasty may enable investigators to better understand the clinical outcomes and disease burdens unique to PTOA. Without proper coding methodology, it is nearly impossible to distinguish indications for surgery at a macro level, thereby leaving many clinical questions unanswered. Furthermore, proper coding practices would enable investigators to retrospectively evaluate the value of care delivered, ensuring that care pathways are in line with organizational standards. Such an approach will also ensure that healthcare organizations are appropriately compensated for the services rendered.

Summary

Posttraumatic osteoarthritis of the hip and knee is a debilitating disease often affecting younger, more active individuals. Currently an estimated 5.8 million individuals are living with PTOA of the hip and knee at a direct and indirect cost of almost $48.9 billion annually. As Americans continue to live active lifestyles, the number of individuals living with PTOA is projected to steadily grow costing billions more dollars in direct and indirect expenditures. It is therefore critical that healthcare providers lobby for improved diagnostic and procedure codes so that PTOA can be properly monitored and objectively evaluated. Through such an approach, providers will have the resources needed to better address the complexities present in PTOA patients. Once granular coding instruments have been developed and used for these complex patients, the full economic impact of PTOA may be realized.

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Part II
Post-traumatic Arthritis of the Upper Extremity

Chapter 4
Post-traumatic Glenohumeral Arthritis

Uma Srikumaran and Eric Huish

Key Points

- Proximal humerus fractures, glenohumeral instability, and direct cartilaginous trauma are all causes of post-traumatic glenohumeral arthritis.
- Various injury patterns and previous interventions may alter the anatomy of the glenohumeral joint, which must be taken into account when surgical treatment is planned.
- Total shoulder arthroplasty, reverse shoulder arthroplasty, and hemiarthroplasty are all utilized in the treatment of post-traumatic glenohumeral arthritis, each with various benefits and shortcomings.
- Non-arthroplasty options for the treatment of glenohumeral post-traumatic arthritis show transient benefit and may be beneficial in the appropriately selected patient.

Introduction

Post-traumatic arthritis of the shoulder can result from a variety of injuries. Fractures, dislocations, isolated chondral injuries, or rotator cuff pathology may be implicated. As with other arthropathies, there is a broad spectrum of disease ranging from mild discomfort to severe disability with pain, stiffness, and inability to

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_4

perform activities of daily living. Appropriate treatment should be based on the initial injury, previous treatment, severity of disease, and patient factors including age, activity level, hand dominance, and goals.

Causes

Fractures

Multiple traumatic etiologies may lead to arthritic changes in the glenohumeral joint. Proximal humerus fractures are among the more commonly implicated injuries with one study showing nearly two-thirds of patients with three- and four-part proximal humerus fractures developed post-traumatic arthritis [50]. This may be due to direct articular damage at the time of injury, malunion with intra-articular step-off, screw cutout, or osteonecrosis (Fig. 4.1). The rate of osteonecrosis reported in the literature varies. A systematic review revealed an overall rate of 2% after nonoperative treatment of all types of proximal humerus fractures [25]. However, nearly half of the included cases in this review were one-part nondisplaced fractures. The three- and four-part subgroups had an osteonecrosis rate of 14%. A separate systematic review looking at proximal humerus fractures treated with open reduction and locked plating showed a 7.9% rate of osteonecrosis [48]. This analysis excluded studies that were limited to two-part fractures but did not give results based on fracture classification. Other studies have shown higher rates of osteonecrosis after open reduction and internal fixation, with up to 35% in one study [19]. Gerber examined the significance of post-traumatic osteonecrosis and showed that all patients with osteonecrosis after proximal humerus fracture had some level of dysfunction compared to a healthy control group. He noted, though, that associated

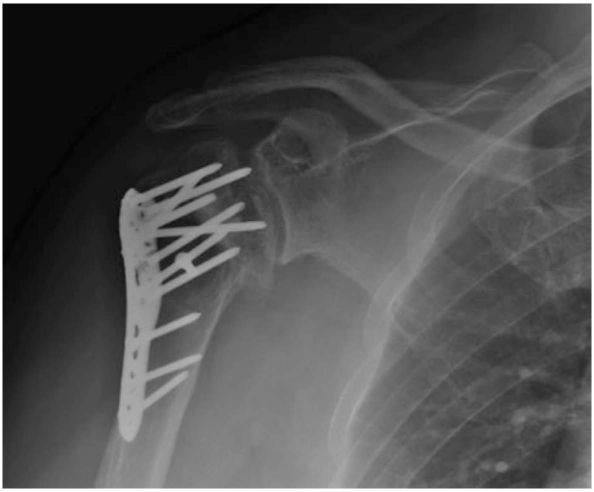

Fig. 4.1 AP radiograph of the shoulder after open reduction and internal fixation of a proximal humerus fracture showing osteonecrosis and collapse of the humeral head with resultant screw protrusion

malunion of the fracture fragments significantly worsened the subjective outcome, pain, forward elevation, and Constant score [20].

Another known complication associated with open reduction and internal fixation is screw cutout, with rates reported as high as 23% overall and up to 43% in patients older than 60 [48, 36]. Articular incongruity has been reported in 67% of malunited proximal humerus fractures [3]. Patients in this study who did not have the incongruity corrected with arthroplasty or shoulder fusion all had unsatisfactory outcomes. Both screw penetration and articular incongruity may alter the contact stresses on remaining intact cartilage leading to post-traumatic arthritis. Further, altered shoulder mechanics or malunion of the tuberosities may also lead to rotator cuff damage and subsequent arthropathy.

While proximal humerus fractures are often implicated in post-traumatic arthritis of the glenohumeral joint, glenoid fractures are less frequently discussed as they are much less common, making up only 10% of scapular fractures, with only 10% of those fractures having significant displacement. Goss recommended 5 mm displacement as a relative indication for treatment with 10 mm as an absolute indication [21]. Fractures with >4 mm step-off were operatively treated, demonstrating good outcomes for DASH scores, SF-36, pain, and return to pre-injury level of activity [1]. Another study with 10-year follow-up after operative treatment had a median Constant score of 94% [42]. Despite good outcomes with intra-articular glenoid fractures and a high tolerance to step-off, recognition of these injuries is still important, as altered glenoid morphology may affect surgical treatment.

Instability

Shoulder dislocations are another potential cause of post-traumatic arthritis (Fig. 4.2a, b). Dislocation arthropathy has been reported to occur at varying rates. One study with 10-year follow-up showed 11% of mild arthropathy with 9% developing moderate to severe arthropathy [23]. Another study showed the presence of arthritis in patients with previous shoulder instability to be 9.2% prior to undergoing surgery [6]. Furthermore, this same study showed development of arthritis in 19.7% of patients after surgery when no arthritis was present preoperatively. It was unclear whether this was a progression from the previous injury or a consequence from surgery. The authors noted that older age at time of first dislocation increased the number of dislocations, and increased follow-up time from surgery were correlated with the development of arthritis. Further, decreased external rotation was also correlated with the development of arthritis. However, it was unknown if this was a cause or a result of the arthritis.

Capsulorrhaphy arthropathy is used to describe arthritis that develops as a result of overtightening the capsule. Matsoukis, who evaluated patients undergoing arthroplasty after previous instability, did not find any significant differences between those with previous surgical treatment of the instability and those without. This finding suggests that dislocation arthropathy and capsulorrhaphy arthropathy may result in similar outcomes after arthroplasty [33].

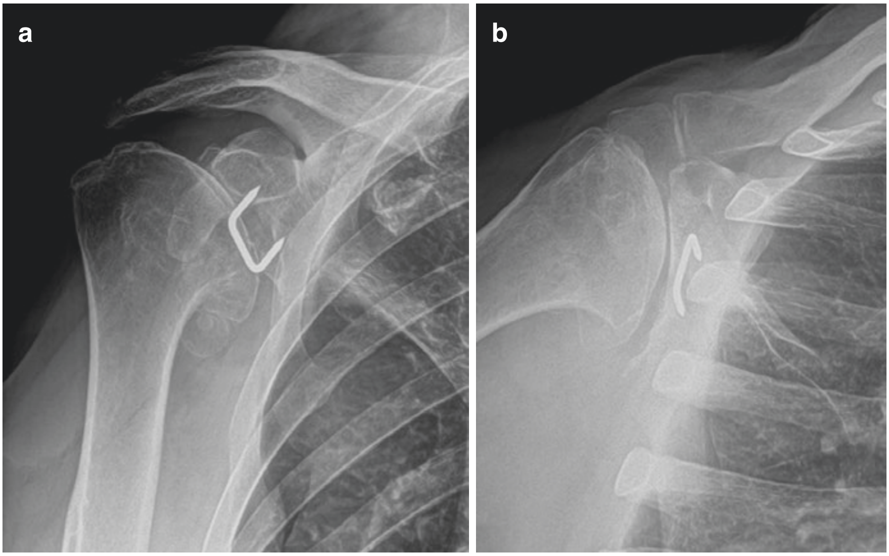

Fig. 4.2 (**a**, **b**) AP and axillary radiographs of a shoulder with post-traumatic arthritis after dislocation and subsequent repair

Other Causes

Other causes of post-traumatic arthritis include isolated chondral or osteochondral injury. Isolated chondral lesions from shearing are rare but have been reported [41], as have osteochondral defects [13]. Arthropathy from rotator cuff tear is more commonly seen in degenerative cases, but may develop after a traumatic tear if ignored. More likely the altered mechanics and anatomy of the joint following trauma may lead to degeneration of the rotator cuff. As with degenerative cases, this pattern is difficult because the lack of rotator cuff function limits treatment options.

Treatment

There are many factors involved in determining the appropriate treatment of post-traumatic glenohumeral arthritis. The surgeon should assess the severity of disease, initial injury, previous treatments, patient age, and functional requirements.

Nonoperative Treatment

The initial treatment of post-traumatic glenohumeral arthritis in all patients should include a trial of nonoperative management. This may include physical therapy, activity modification, medications, or injections. Both corticosteroid and viscosupplementation (hyaluronic acid) injections may be considered, though use of viscosupplementation in the shoulder is off-label. The American Academy of Orthopaedic Surgeons guidelines on the treatment of glenohumeral arthritis are inconclusive on the efficacy of physical therapy, pharmacotherapy, and corticosteroid injections. Further, there was limited evidence found to support viscosupplementation [26]. Only after these modalities have been attempted, surgery should be considered only in a carefully selected patient population, as patients with low demands and multiple medical comorbidities may be best managed with continued observation.

Preoperative Evaluation

Workup prior to possible surgical intervention should be thorough. Standard radiographs should be taken to evaluate joint space, arthritic changes, and other abnormalities including malunion or nonunion of previous fracture and the presence of hardware. Further imaging with CT or MRI may be warranted to evaluate glenoid morphology, rotator cuff integrity, or other soft tissue abnormalities. Careful attention should be paid to a thorough neurological exam as nerve injuries may result from the initial trauma or possibly from previous interventions. In such cases, thorough neurologic exam, an EMG, and NCS may be required.

Any previously operated shoulder should be ruled out for infections and possible source of pain and dysfunction. High rates of positive cultures have been reported in patients undergoing revision shoulder surgery [24]. *Propionibacterium acnes* is often indicated and may be missed unless cultures are held for an extended period of time for this more indolent organism. Preoperative lab work including WBC, ESR, and CRP along with intraoperative frozen sections does not have a high sensitivity for indolent infection [49]. More recently synovial cytokines have been investigated as predictors of periprosthetic joint infections [17] and may lead to improved detection. If infection is discovered, it should be addressed appropriately.

Preoperative planning should include assessment of prior incisions/approaches as well as determination of any hardware that may require removal. The choice of the appropriate surgical procedure is controversial and should be tailored to the individual patient.

Arthroplasty

Total Shoulder Arthroplasty

Arthroplasty is often chosen for treatment of post-traumatic glenohumeral arthritis. In these cases it is important to recognize anatomic changes resulting from previous injury or surgery. Malunited fractures may alter the relationship between the humeral head and shaft making the placement of a humeral stem difficult. Possible solutions include using short stem prostheses (Fig. 4.3a, b) or stemless prostheses. Tuberosity malunion also causes difficulty as arthroplasty components are not designed to address the tuberosities and will not correct malunions that may be a

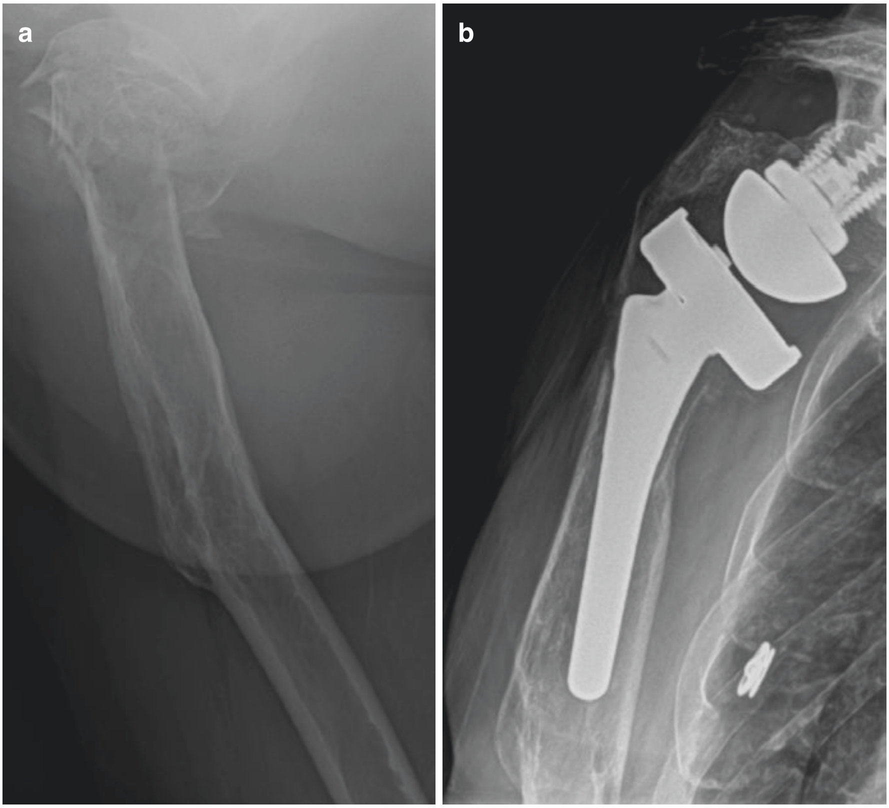

Fig. 4.3 (**a**, **b**) Preoperative and postoperative radiographs of a humerus with malunion and post-traumatic arthritis treated with reverse shoulder arthroplasty utilizing a short humeral stem

source of impingement and dysfunction. If malunion is severe, osteotomy may be required. The need for tuberosity osteotomy has been shown to result in poorer outcomes [5]. Glenoid degeneration or fracture may also make arthroplasty difficult. Ensuring adequate fixation as well as appropriate version is crucial. Glenoid augments have been developed to treat posterior glenoid wear and recently have been used as an anterior glenoid augment, which may be useful after anterior instability with bony Bankart lesion [28]. Soft tissue changes must also be addressed. Green reported that 65% of patients undergoing arthroplasty after previous instability repair required subscapularis lengthening and anterior capsular release. Eighteen percent required glenoid bone grafting, and one required glenoidplasty [22].

Hemiarthroplasty

Hemiarthroplasty, sometimes used as an acute treatment in trauma, may also be used to treat sequelae of the injury, including arthritis. Since osteonecrosis and malunion are typically limited to the humerus, a hemiarthroplasty may be used to replace the affected surfaces. However, hemiarthroplasty used to treat fracture sequelae showed the lowest survival and highest complication rate when compared to other uses of the implant [18]. Further, studies have shown better pain scores, satisfaction, and survival with a lower reoperation rate after total shoulder arthroplasty than hemiarthroplasty when used specifically for post-traumatic osteonecrosis of the humeral head [44]. Specifically looking at patients younger than 55, total shoulder arthroplasty had outperformed hemiarthroplasty with regard to survivability, pain, motion, and satisfaction [2]. Another study evaluating patients under 50 showed a similar benefit in survival and satisfaction favoring total shoulder arthroplasty [15]. That said, some surgeons try to avoid total shoulder arthroplasty in younger patients despite the known facts of glenoid loosening and increased implant failure over its lifetime [37]. However, the increased survival of total shoulder arthroplasty at 15 years suggests this may be becoming less of a concern [44].

The possibility of poor outcomes with hemiarthroplasty alone coupled with a desire to avoid glenoid instrumentation in young patients has led to a search for variations on the technique that may prove superior. One of these techniques known as the "ream and run" utilizes glenoid reaming without instrumentation at the time of hemiarthroplasty. This, however, is a not widely used and technically difficult procedure with a steep learning curve [32]. Another trialed modification to hemiarthroplasty is biologic resurfacing of the glenoid. Various materials have been used for resurfacing, including meniscus and acellular matrices. Some studies have shown success [31], but high rates of early failure have been reported [39, 47] and the procedure is not routinely performed. Other areas of interest for modifying hemiarthroplasty include use of pyrocarbon implants [8]. Although success has been seen in other joints, studies of its use in the shoulder are lacking.

To this end, the choice between hemiarthroplasty and total shoulder arthroplasty is still debated, especially for young patients.

Humeral Resurfacing

An alternative to hemiarthroplasty is humeral resurfacing. Without addressing the glenoid, the aim is to maintain as much bone as possible so to prevent issues that may arise at the time of revision. Its use has been reported for sequelae of proximal humerus fractures with good results [30, 38]. However, with the advent of stemless humeral prostheses, these are no longer the only bone-conserving option.

Reverse Shoulder Arthroplasty

If the rotator cuff is deficient, in presence of a functional deltoid and adequate bone stock, a reverse shoulder arthroplasty may be considered. Although clinical outcomes for the treatment of fracture sequelae show improvement, results are worse than for acute fractures [10, 14]. To this end, patients who had previous fracture surgery had worse outcomes than those treated initially nonoperatively [10].

Reverse shoulder arthroplasty has also been used with good results as a revision from a failed hemiarthroplasty due to development of glenoid arthritis or rotator cuff failure [29]. However, these results are inferior to those obtained for primary indications.

Reverse shoulder arthroplasty was originally reserved for elderly patients; however, in cases where no other option seems appropriate, reverse shoulder arthroplasty may be an option in a younger patient. Few studies evaluate patients under 60 undergoing reverse shoulder arthroplasty. The current literature shows good early outcomes, but follow-up is limited, and the success rate and patient satisfaction are less than in previous studies looking at an older population [35, 45]. This procedure must be done with caution in a young patient, as long-term outcomes are not yet widely reported with midterm outcomes showing a 15% failure rate, 25% reoperation rate, and 38% complication rate after 5–15 years [16].

Alternative Options

If reverse shoulder arthroplasty is determined to be inappropriate due to patient age, poor glenoid bone stock, nonfunctional rotator cuff, or other reasons, a cuff tear hemiarthroplasty is an alternative. In the most severe cases, where both rotator cuff and deltoid are nonfunctional or where significant brachial plexus injury has occurred, a glenohumeral fusion may be considered. This results in significant impairment compared to normal shoulder function, but remaining scapulothoracic motion may allow for utilization of remaining hand/elbow function in the appropriately selected patient [11].

Non-arthroplasty Surgery

Especially in young patients, non-arthroplasty options may be more attractive to treat post-traumatic glenohumeral arthritis. Arthroscopic debridement has been shown to improve pain and function in 88% of patients with grade IV glenohumeral joint chondral lesions for an average of 28 months [7]. Lesions over 2 cm^2 were associated with failure and recurrence of pain, while microfractures have been shown to improve pain scores, American Shoulder and Elbow Surgeons' scores, and the ability to return to work/activity at 47 months [34]. This study, however, had a 19% failure rate, defined as need for additional surgery. The greatest improvements were seen in isolated humerus lesions. Failure was associated with a larger defect size. Osteochondral autologous transplantation was shown in two cases only by Scheibel to improve Constant scores and have good integration via MRI and by second-look arthroscopy [43]. All patients in this study had evidence of arthritis at latest follow-up, including those with worsening of preexisting arthritis.

Osteochondral allografts have been reported as an alternative solution without the risk of donor site morbidity [27]. Autologous chondrocyte implantation was shown to be effective at 1 year in a case report but has also been reported to cause overgrowth and mechanical damage due to the thin humeral head cartilage [9, 40]. Juvenile cartilage allograft and subchondral calcium phosphate injections have not been described in the literature but may be an area of future research.

Biologic resurfacing of the glenoid is an alternative and not widely used method with a failure rate of up to 28% [12]. That said, as none of these treatments have shown consistent long-term relief of arthritis pain, they may be considered as a temporary solution for patients who are not candidates for arthroplasty due to age, medical condition, or other reasons.

Complications

Postoperative stiffness is a common complication of surgery for post-traumatic arthritis of the glenohumeral joint. Accordingly, attention should be turned to adequate soft tissue release at the time of surgery and an emphasis placed on postoperative physical therapy. Progression of arthritis may also develop after non-arthroplasty surgery or hemiarthroplasty. Component failure is also possible and reported as 5.3% for the glenoid and 1.1% for the humerus in a broad review of shoulder arthroplasty performed for any indication [4]. Long-term studies are lacking for many of our current implants and may change survival data. Other complications in this review include instability in 4.9%, periprosthetic fracture in 1.8%, and nerve injury in 0.8% [4]. Most concerning is infection. The infection rate after revision shoulder arthroplasty has been shown to be 3.15% compared to 0.76% in primary arthroplasties at the same institution [46]. These risks must be considered when selecting the appropriate patient and determining the appropriate treatment.

Summary

The treatment options for post-traumatic arthritis of the glenohumeral joint are as diverse as its causes. Patients are surgical candidates only after failure of nonoperative treatments and thorough preoperative workup. While arthroplasty may be a widely accepted treatment for older or lower-demand patients, there is controversy surrounding the treatment of younger, active patients. In this group, surgical treatment should be individualized after frank discussion of goals and expected outcomes. While significant improvements are seen after surgical intervention, they tend to fall short of expected results for primary procedures with high complication rates. New and emerging implants and techniques may improve treatment in these challenging cases.

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Chapter 5
Post-traumatic Arthritis of the Elbow

Kevin O'Malley, Ryan Churchill, Curtis M. Henn, and Michael W. Kessler

Key Points
- The risk of post-traumatic arthritis of the elbow is very high after articular injuries.
- CT arthrography is an excellent modality to assess intra-articular abnormalities.
- Intra-articular glucocorticoid injections have no efficacy in this population.
- Several operative options are available in cases of failure of conservative management.

Introduction

Post-traumatic elbow arthritis is relatively common with a reported risk of 44% following articular fractures [1]. Historically, this risk has been well recognized with Dr. Bigelow [2] writing in 1868 "There is no class of injuries so frequently productive of discontent, and perhaps so often the cause of litigation, as traumatic lesions of the elbow joint." Elbow fracture management continues to progress from predominantly nonoperative management to operative treatment in line with principles as shown by Jupiter in 1985 [3]. Treatment of these fractures is complex requiring an understanding of the various nonoperative and operative treatment modalities as well as understanding possible complications such as malunion, nonunion,

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_5

stiffness, avascular necrosis, heterotopic ossification, and post-traumatic arthritis. In this chapter we will outline the diagnosis and surgical management of post-traumatic elbow arthritis as well as case examples to further describe treatment options and techniques.

Elbow fractures account for 6% of adult fractures with $\frac{1}{3}$ of these fractures involving the distal humerus, $\frac{1}{3}$ to $\frac{1}{2}$ involving the proximal radius, and the remainder involving the proximal ulna. Fractures follow a bimodal age distribution with higher rates seen in young males and elderly females [4].

Post-traumatic osteoarthritis of the elbow is a multifactorial consequence of the initial trauma, the biologic response to the trauma, and the alterations in load distribution that result from articular incongruity and instability [1].

Relatively few studies have analyzed the development of post-traumatic arthritis following elbow injuries. From the available literature, it appears intra-articular distal humerus fractures have the highest rate of post-traumatic arthritis [5–7]. Guitton et al. analyzed radiographs of 139 patients following surgical treatment of an elbow fracture with over 10 years of follow-up. They found mechanisms of injury, age, gender, follow-up duration, occupation, and limb dominance not to be associated with radiographic arthrosis. However, patients with bicolumnar distal humerus, capitellum, and elbow dislocations were more likely to develop post-traumatic radiographic arthrosis [6]. Interestingly, although radiographic arthrosis is present in a high percentage of patients (80% per Doornberg et al.), functional scores do not appear to correlate. Instead, pain, flexion arc, and limb dominance appear to be the most important predictors of functional elbow scores [7, 8]. Notably, none of the 30 patients followed by Doornberg 12 years after intra-articular distal humerus fracture underwent total elbow arthroplasty (TEA) as a consequence of their fracture. Only one patient underwent arthrodesis for symptomatic post-traumatic arthritis [7].

Radial head and neck fractures also show little correlation between radiographic degenerative changes and symptomatic elbow pain [9]. Burkhart showed ulnohumeral arthritis in 12 of 17 patients at an average of 8.8 years following a proximal radius fracture. Again, there was no correlation of radiographic arthrosis to functional scores (Mayo Elbow Performance Score (MEPS) and Disabilities of the Arm, Shoulder and Hand Questionnaire (DASH)) or pain [10].

Long-term data on proximal ulna fractures is limited. Rochet et al. reported on 18 patients with proximal ulna fractures and found 6 to have grade 1 osteoarthritis based on the Broberg and Morrey classification. In comparison to other elbow fractures, olecranon fractures specifically show relatively low rates (20% or less) of post-traumatic arthritis, with articular displacement over 2 mm being the most important risk factor [11, 12].

Classifying post-traumatic elbow arthritis is typically done with the Broberg and Morrey (BM) classification, which is divided into three grades: grade 1 with slight joint space narrowing with minimal osteophyte formation, grade 2 with moderate joint space narrowing and moderate osteophyte formation, and grade 3 showing severe degenerative changes with gross joint destruction [13]. Another classification is the Hasting and Rettig (HR) classification, which like the BM classification is also divided into three grades and has no significant difference in comparison to the

BM classification [14]. Lastly, the Morrey classification can be utilized to describe bone defects of the distal humerus and maybe useful for the preoperative planning [15].

Closely related to post-traumatic elbow arthritis is post-traumatic elbow stiffness. While stiffness specifically is outside the scope of this chapter, it is important to have a basic understanding of post-traumatic stiffness when approaching complex post-traumatic elbow conditions. Our understanding of post-traumatic elbow stiffness continues to grow, and as of today we know that stiff elbows show an increased inflammatory cytokine and myofibroblast infiltration [16]. Stiffness is typically classified into two groups: extrinsic stiffness due to soft tissue and extra-articular processes and intrinsic stiffness secondary to articular pathology [17]. It is important to note the functional arc of the elbow, defined as flexion-extension motion of 30° to 130° and pronosupination of 50° to 50° [18]. Achieving functional range of motion typically occurs in the first 6 months following surgery with minimal range of motion progression after 6 months [19].

History and Physical Exam

Operative planning for post-traumatic elbow arthritis begins with a thorough history and physical. The history should include the initial injury mechanism, initial injuries sustained (fractures and instability), previous operative and nonoperative treatment (especially ulnar nerve management), and any history of infection or soft tissue procedures. Detailed information on symptomatic pain and stiffness should be obtained. For example, pain throughout the range of motion suggests diffuse arthritic changes, while terminal pain suggests impingement by an osteophyte or soft tissue [20]. Pain at rest carries a wider differential diagnosis including infection, cervical spine radiculopathy, soft tissue disease, and reflex sympathetic dystrophy [21]. Patient expectations and lifestyle factors must also be addressed as a manual laborer will have different functional demands and expectations when compared with a sedentary desk worker.

The physical examination should include a thorough inspection of the entire extremity to assess prior surgical incisions for both fracture treatment as well as soft-tissue coverage procedures. Hand thenar musculature should also be assessed (i.e., intrinsic hand wasting). Neurologic evaluation should assess upper extremity sensory and motor function as well as ulnar neuritis specifically. The patient's elbow range of motion should be tested and any painful points should be noted. Collateral ligament stability of the elbow should also be evaluated.

Imaging evaluation should be aimed at obtaining a complete understanding of the degree of arthritis, loose bodies, current hardware, and bone stock. Orthogonal elbow radiographs are the standard initial imaging study. If the patient also complains of wrist pain, full-length forearm and wrist views should be obtained to assess for a potential Essex-Lopresti lesion. Computed tomography (CT) is typically required for further evaluation and is more effective than conventional radiography in assessing osseous causes of elbow stiffness [22]. CT arthrography has been shown to provide improved assessment of intra-articular abnormalities such as osteocartilaginous bodies, hyperplastic synovium, and osteophytes [23]. While three-dimensional (3D) CT has not been evaluated for preoperative planning in this population, we find it extremely helpful for procedures such as arthroscopic or open debridement in patients with large osteophytes and loose bodies. Other diagnostic tests may include electromyographic evaluation in patients with a concerning exam for neuropathy or an entrapment syndrome.

Treatment

Nonsurgical Treatment

Conservative management of post-traumatic elbow arthritis is typically limited to patients with mild arthrosis or low-demand patients. Activity modification, nonsteroidal anti-inflammatory medication, and physical therapy should be considered with an emphasis on maintaining range of motion and reducing painful activities. Intra-articular glucocorticoids may be considered, but have no evidence of efficacy in this population. Viscosupplementation with hyaluronic acid has been shown to result in slight short-term pain relief and activity impairment 3 months following an injection series. However, at 6 months no benefits were shown suggesting it is not useful for long-term treatment [24].

Surgical Treatment

Several operative options are available once nonsurgical measures have been exhausted. Surgical options include arthroscopic or open osteocapsular debridement arthroplasty, interposition arthroplasty, partial joint arthroplasty (e.g., distal humerus hemiarthroplasty or radiocapitellar arthroplasty), total elbow arthroplasty (TEA), and elbow arthrodesis. Sears and colleagues [15] described an algorithmic approach to selecting the appropriate surgical intervention for post-traumatic elbow osteoarthritis. For patients who have pain at the terminal arc of motion, they recommended arthroscopic or open debridement arthroplasty with possible ulnar nerve transposition. For the patient who has pain throughout the entire arc of motion, they describe the use of partial joint arthroplasty for arthritic changes isolated to the radiocapitellar joint or distal humerus and interposition arthroplasty or total elbow arthroplasty for the patient with diffuse osteoarthritic changes. For younger patients who have exhausted most surgical options and do not wish to have 10 pound weight restriction on their extremity from a total elbow arthroplasty, elbow arthrodesis is offered.

Osteocapsular Debridement Arthroplasty

Open and arthroscopic osteocapsular debridement arthroplasties are good options for the patient with mild to moderate arthritis and pain at the terminal aspects of range of motion [25–34]. Open osteocapsular debridement arthroplasty is usually reserved for patients who have a preoperative flexion contractures greater than 90 degrees, preoperative ulnar neuropathy or documented ulnar nerve EMG changes, hardware that needs to be removed, or where arthroscopic debridement is exceptionally difficult [25, 34]. Open procedures include the Outerbridge-Kashiwagi procedure, Morrey ulnohumeral debridement arthroplasty, and the column procedure. In the Outerbridge-Kashiwagi procedure, the patient is positioned in the lateral decubitus with the involved extremity draped free. A posterior midline incision is utilized with a triceps split to visualize the posterior compartment of the elbow. Osteophytes and loose bodies are removed and the capsular undergoes debridement. The olecranon fossa is then fenestrated with a drill to allow limited access to the anterior compartment of the elbow. Loose bodies are removed and any osteophytes about the coronoid are removed. If the patient has a preoperative flexion contracture greater than 90 degrees and less than 90 to 100 degrees of flexion, the posterior band of the medial ulnar collateral ligament (MUCL) should be released, and consideration should be given to transpose the ulnar nerve. If the patient has a preoperative ulnar neuropathy or documented ulnar nerve EMG changes, then the patient should undergo ulnar nerve release and transposition [15, 25]. The column procedure involves utilizing a lateral column approach to the elbow to perform anterior and posterior compartment debridement arthroplasty with care to preserve the lateral ulnar collateral ligament during the procedure. If there is a significant preoperative flexion contracture or ulnar neuropathy, then a separate medial incision is made to address the ulnar nerve and posterior band of the MUCL [25, 35].

Arthroscopic adaptations for osteocapsular debridement have shown good results with the benefit of greater soft tissue preservation and quicker return to activities [26–33, 36]. Relative contraindications to elbow arthroscopy are related to aberrant anatomy of the ulnar and radial nerve from either prior trauma or surgeries. Additionally, in cases where there is severe arthritis arthroscopic debridement may be difficult to complete given the difficulty in gaining access to the joint. In these cases consideration should be given to open identification and protection of the nerve if arthroscopy is undertaken. Savoie and O'Brien[34] described a comprehensive arthroscopic approach to elbow arthritis. To begin, the patient may be positioned prone or lateral decubitus (Fig. 5.1a). A non-sterile or sterile tourniquet may be used. The course of the ulnar nerve is palpated and marked (Fig. 5.1b). The elbow is insufflated utilizing an 18-gauge needle and 20 to 30 milliliters (mL) of sterile saline injected in the area of the soft spot portal or posterior central portal. Next the site of the anteromedial portal is marked 2 centimeters (cm) superior and 2 cm anterior to the medial epicondyle. Only the skin is incised and a 4 millimeter (mm) cannula with a blunt trocar is used to enter the joint. Occasionally this may be difficult and a hemostat may be needed to open the joint capsule. The anterolateral

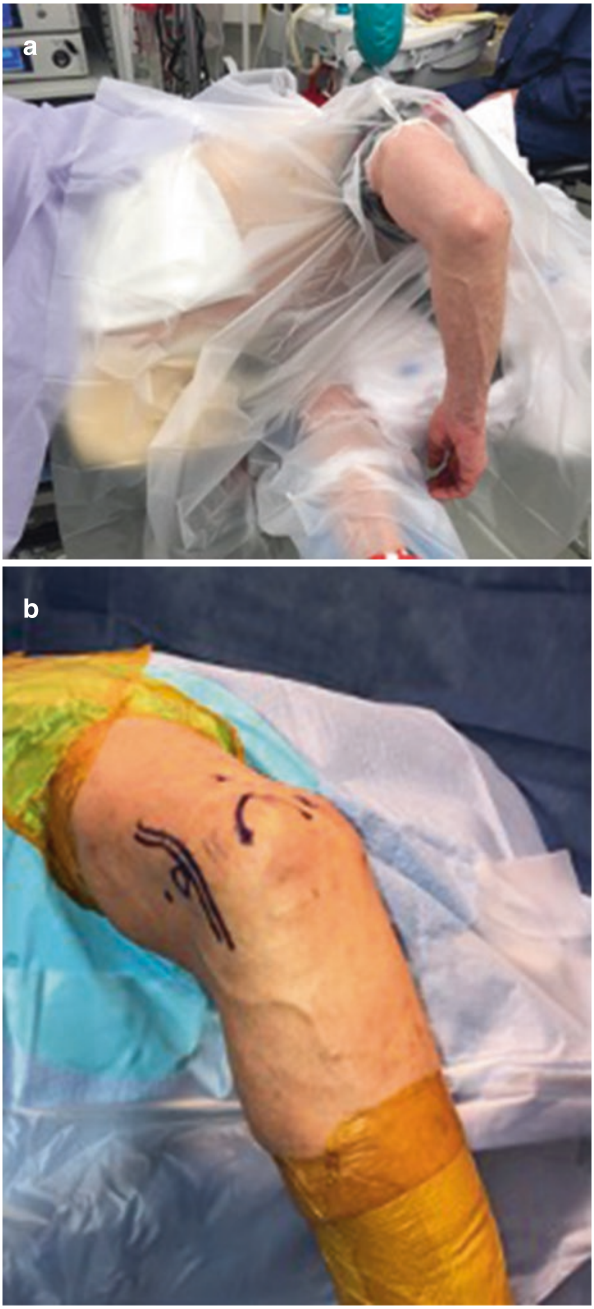

Fig. 5.1 (**a**, **b**) The photo on the left demonstrates lateral decubitus patient positioning in preparation for elbow arthroscopy. The photo on the right demonstrates landmarks for medial portal placement including the ulnar nerve and the medial epicondyle

Fig. 5.2 Lateral landmarks for portal placement are drawn out with the overlying incisions for the anterolateral, posterior central, and posterolateral portals shown

portal is then established under direct visualization utilizing a spinal needle. The spot for the portal is typically 2–3 cm anterior the lateral epicondyle and at the superior most aspect of the capitellar cartilage (Fig. 5.2). The procedure proceeds then in a stepwise manner beginning with a diagnostic arthroscopy followed by removal of any loose bodies from the anterior compartment along with osteophytes and synovitis. If the radiocapitellar joint is significantly involved, a radial head resection may be performed through the soft spot portal. Prior to proceeding to the posterior compartment, a fenestration hole is created through the olecranon fossa. Other options include a combined arthroscopic and open procedure with arthroscopic debridement being carried out anteriorly followed by a mini-open posterior elbow debridement. This can be effective when the elbow has more severe arthrosis that may require treatment both laterally and medially in the anterior elbow.

A posterior central portal is created 3 cm proximal to the tip of the olecranon and this serves as the initial viewing portal. A posterolateral portal is made parallel to the posterior central portal just outside the triceps tendon. Once these portals are established, the posterior compartment is debrided, loose bodies removed, and synovectomy performed. The medial and lateral gutters are inspected for loose bodies and plica that may be contributing to the pathology. Finally the tip of olecranon is excised and if necessary the anterior capsule is released. If the patient had preoperative symptoms of ulnar neuropathy, the ulnar nerve may be decompressed in situ. Patients are allowed full range of motion immediately postoperatively without weight-bearing restrictions.

Recent literature has found overall good to excellent results with this procedure in appropriately selected patients with mild to moderate arthritis [25–33, 36]. DeGreef et al. found good results in a cohort of patients with a mean age of 50 years old who underwent arthroscopic osteocapsular debridement with an increase in range of motion (ROM) from 94 to 123 degrees, a significant decrease in pain scores, and an increase in the Mayo Elbow Performance Index (MEPI) by an average of 34 points [37]. These results are reflected in much of the recent literature [25–33, 36]. Galle and colleagues reviewed a consecutive series of 46 patients who underwent arthroscopic osteocapsular debridement. The mean age of the patients in their study was 48 years. They found a significant increase in ROM (final ROM arc 12 degrees to 135 degrees), a decrease in pain, and an increase in the Mayo Elbow Performance Score (MEPS) from 57 preoperatively to 88 postoperatively. Furthermore they had no complications in their cohort of patients [28]. Finally, Lim et al. investigated the preoperative factors associated with outcomes after arthroscopic osteocapsular debridement. Through multivariate analysis they found that preoperative range of motion was the main factor that affected postoperative elbow function and range of motion, and through further analysis preoperative arc of motion greater than 80 degrees was found to be the cutoff for improved postoperative function and arc of motion [30].

Interposition Arthroplasty

Given that the majority of patients with post-traumatic elbow arthritis tend to be younger and of higher demand, interposition arthroplasty serves as a valuable surgical tool in treating this condition in patients who do not wish to have the weight-bearing and activity restrictions associated with TEA. Options for interposition arthroplasty include both autograft (e.g., anconeus, fascia lata) and allograft (e.g., Achilles tendon, fascia lata, dermis) [15, 25]. Contraindications to this procedure include active infection, gross elbow instability or deformity, open physes, no flexor-pronator power, and patients with deficient bone stock about the elbow [25, 38, 39].

As described by Morrey [40], this procedure is performed with the patient positioned in supine or lateral decubitus position. A posterior approach to the elbow is typically utilized. Kocher's interval is then developed between the extensor carpi ulnaris and the anconeus. The lateral ulnar collateral ligament (LUCL) and elbow extensors are released from the lateral epicondyle and tagged. A capsular release is performed and osteophytes are removed. Next the ulnar and humeral articular surfaces are prepared so a congruent articulation is obtained and enough bone is resected so that there is 2–3 mm of laxity to ensure that the joint is not overstuffed. Following this, three to four drill holes are created in the humerus, and the graft is prepared with three to four horizontal mattress sutures that are passed through the drill holes to secure the graft to the distal humerus surface. The joint is then reduced and range of motion assessed for areas of impingement. Finally, the stability of the MUCL is assessed and the LUCL and the extensors are repaired back to the lateral epicondyle. If the LUCL is unable to be repaired, then reconstruction should be performed. Occasionally a hinged external fixator is placed to protect collateral ligament reconstruction when performed. Patients are allowed range of motion on postoperative day 1.

While interposition arthroplasty provides a good option for improved pain and range of motion for the young, active patient, the results tend to be inferior to elbow arthroplasty [25]. Baghdadi et al. reported the results of 39 patients treated with anconeus interposition arthroplasty with an average of 10 years of follow-up. They found 72% of their cohort had good to excellent results with significant improvements in their MEPS. However, they did find a 24% reoperation rate and 7% complication rate in their cohort [39]. Cheng and Morrey described the results of interposition arthroplasty using fascia lata in 13 patients. They found good to excellent results in 62% of the patients with eight complications in six patients and four patients requiring conversion to TEA at an average of 30 months [41]. Furthermore, Larsen and Morrey reported the results of 38 interposition arthroplasties performed with Achilles tendon allograft in a cohort of patients with an average age of 39 years. They found that at an average of 6 years of follow-up, there were significant improvements in range of motion (51° to 97°) and MEPS. Although 29% of patients had a poor result with 18% requiring revision surgery, 88% of all patients reported they would undergo the procedure again. Hence the authors concluded that interposition arthroplasty is a valid salvage procedure for the young patient with severe arthritis, limited motion, and no instability [42].

Radiocapitellar Arthroplasty and Distal Humerus Hemiarthroplasty

There is a relative paucity of literature on radiocapitellar arthroplasty and distal humerus hemiarthroplasty. Currently they are an off-label for treatment of osteoarthritis in the United States, and the situations in which they would be utilized for post-traumatic osteoarthritis are very limited [25]. The studies on distal humerus hemiarthroplasty largely are focused on the use for acute treatment of non-reconstructable elbow fractures. While these studies show relatively good outcomes, they have short-term follow-up and are predominantly in elderly patients [43, 44]. For patients with isolated radiocapitellar arthritis, the use of a radiocapitellar replacement has been described. Heijink and colleagues reported the results of six patients treated with radiocapitellar arthroplasty with an average of 50 months of follow-up. The patients in the study had improvements in range of motion, their DASH scores, MEPS, and pain levels. Overall they had three excellent and three good results with 100% survivorship of implants. An added benefit to radiocapitellar arthroplasty is that it maintains the valgus and external rotation stability of the joint [45]. These results are limited, and further literature and expansion of the recommendations for the use need to occur before this intervention can become standard treatment.

Total Elbow Arthroplasty

Total elbow arthroplasty remains the final operative choice for the majority of patients who have failed other operative interventions. It remains the definitive functional treatment for elderly patients with severe end-stage post-traumatic osteoarthritis. It is not ideal for young active patients with post-traumatic arthritis especially in cases of instability due to increased rates of mechanical wear and the need for early revision [15, 25].

The majority of TEA performed today utilizes a linked semi-constrained prosthesis. In addition to this design, there are unlinked TEA that rely on soft tissue balancing and implant conformity to provide stability. By the nature of being unlinked, these designs result in decreased bone-cement interface stresses and allow load sharing between the implant and the soft tissues. However, an inability to balance the soft tissues is a contraindication to use of this design and as such is not applicable to the majority of patients with post-traumatic osteoarthritis [25].

Procedure

When performing TEA the patient is positioned supine or in lateral decubitus. A sterile tourniquet is routinely used. A variety of deep approaches may be utilized. Originally Bryan and Morrey described elevating the triceps from medial to lateral to expose the joint. This approach can lead to higher rates of postoperative triceps insufficiency, and therefore in recent years, triceps-sparing approaches have seen an increase in utilization. With a triceps-sparing approach, the triceps is left in continuity with windows established medially and laterally for implant placement. After adequate exposure and soft tissue release, the distal humerus and ulna are prepared. This typically includes resection of the tips of the olecranon and coronoid processes. Additionally, the proximal ulna often requires a combination of a bur and bone rasp to allow for entry of trial components. Once trial implants are inserted, bony impingement should be assessed and any sites of impingement resected. Also, in cases where there is concomitant radiocapitellar arthritis, the radial head can be excised with careful resection as the posterior interosseous nerve will be just anterior to the radial head. Once trials are placed and impingement sites addressed, a mini C-arm can be used to confirm appropriate placement. Lastly, in patients with preoperative ulnar nerve symptoms, transposition should be considered. On postoperative day 1, unrestricted range of motion is allowed, but patients are limited to a 1-pound lifting restriction for the first 3 months and nothing heavier than 10 pounds for life.

Studies on TEA in the younger patients suffering from post-traumatic osteoarthritis have been increasing. Schoch et al. recently performed a retrospective review of 11 patients under 50 years old undergoing TEA with a mean follow-up of 3.2 years. They found improvements in pain scores, MEPS, DASH scores, and range of motion. While these are positive results, they reported an 82% complication rate with six mechanical failures (54%) and as such recommended caution when performing TEA in this young patient population [46]. These results correlate to similar complications with mechanical failure and loosening as reported in several earlier studies [47–52].

While there are high complication rates in the young adult population throughout the literature, a successful TEA does improve function and decrease pain. Park et al. reported the results of TEA performed in 23 patients under 40 years old with post-traumatic arthritis with average follow-up of 10.8 years. The authors found significant decreases in pain scores and increased MEPS with improved range of motion with increasing arc of motion from 37.8° to 120.6°. Furthermore, they reported 95% and 89% implants survival rates at 8 and 15 years, respectively [53]. Welsink et al. performed a systematic review of TEA including all indications. Their review included 70 articles with 9379 TEA performed with three different implants. There was an average follow-up time of 81 months of follow-up across all articles. They found for the newer Coonrad-Morrey-style prosthesis that there was an 87.2% survival at 7 years for all indications with a mean range of motion of 30° to 129° with significant improvement in outcomes. They reported an overall 11–38% complication rate with implant loosening being the most common complication (7%) [54]. Furthermore aseptic component loosening is the most common cause for revision TEA (38% of revisions) as demonstrated by Prkic et al. in a systematic review on causes of TEA failure [55].

Elbow Arthrodesis

Elbow arthrodesis remains a treatment option for a very specific patient: the relatively young patient with severe unilateral post-traumatic elbow arthritis who cannot tolerate weight-bearing limitations required for TEA and who is not a candidate for interposition arthroplasty. Historically, elbow arthrodesis has not been tolerated well because the adjacent joints do not compensate well for the motion loss seen with arthrodesis [25].

Arthrodesis may be achieved with compression across the joint utilizing bent plates, Ilizarov frames, compression screws, and cross strut grafts [25, 56, 57]. When performed, the elbow is typically fused at 90° of flexion although arthrodesis at 30° to 45° may be considered for patients who require a specific position for employment or for patients with lower extremity disorders that require the use of the elbow and forearm for transfer. Patient input into the final elbow position can be obtained by placing patients in a hinged elbow brace with varying degrees of flexion. This allows a patient to “try out” the fusion position that will work best for them [40].

Conclusion

Our understanding of post-traumatic elbow arthritis continues to evolve. The development of elbow arthritis is a complex interplay of factors including the initial trauma, the biologic response to the trauma, and the alterations in load distribution over time [1]. Radiographic signs of arthritis are relatively common especially with intra-articular distal humerus fractures. However, patient symptoms and goals need to be appropriately identified and addressed as many patients with radiographic arthritis are relatively asymptomatic and the operative treatment course can result in significant complications and require lifestyle alterations [7]. Conservative management of elbow arthritis includes activity modification, NSAIDs, and physical therapy. Intra-articular injections have little evidence to support long-term efficacy. Surgical treatment includes arthroscopic and open debridement, interposition arthroplasty, partial joint arthroplasty, total elbow arthroplasty, and elbow arthrodesis with each modality having distinct possible benefits and complications.

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Chapter 6
Post-traumatic Arthritis of the Wrist

Sophia A. Strike and Philip E. Blazar

Key Points

- Radiocarpal and intercarpal arthritis, when caused by scapholunate ligament injury or scaphoid nonunion, allow for treatment options based on predictable patterns of degenerative change.
- Radiocarpal, ulnocarpal, and distal radioulnar joint arthritis may be caused by intraarticular fractures of the distal radius or distal radius malunion.
- Isolated intercarpal arthritis can occur from less common injuries to the carpus and associated ligaments.

Introduction

The wrist joint is a complex structure involving articulation of the eight carpal bones and the forearm. Surrounding ligamentous structures maintain the normal static and dynamic relationships of the osseous components. Alteration of the anatomic relationships through fracture, dislocation, or ligamentous injury can cause abnormal carpal kinematics and, eventually, lead to articular degeneration. Pain, instability, loss of motion, and deformity may negatively impact function. Functional wrist motion has been reported at 5 degrees of flexion, 30 degrees of extension, 10 degrees of radial deviation, and 15 degrees of ulnar deviation [1]. The motion required to

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_6

perform daily activities will be unique to each patient based on functional demands and compensatory mechanisms [2]. While traumatic injury remains a common cause of arthritis of the wrist, atraumatic etiologies including inflammatory arthritis, crystalline deposition, hemophilia, and primary osteoarthritis must be considered in the evaluation of these patients [2].

Traumatic etiologies of wrist arthritis include injury to intercarpal, radiocarpal, ulnocarpal, or radioulnar ligaments in isolation or as part of a perilunate injury, nonunion (or malunion) after scaphoid fracture, as well as malunited distal radius fractures [3, 4, 9]. All of these injuries can induce abnormal carpal mechanics and over time cause pain and joint degeneration [3–6].

Posttraumatic arthritis may occur in predictable patterns throughout much of the wrist as will be discussed in the chapter. This allows treatment to be tailored to the stage of degeneration. The natural history of wrist injuries has been described in cases such as scaphoid nonunion and distal radius fracture malunion but is less clear for intercarpal injury such as scapholunate ligament injuries [13–15]. Surgical management of arthritis typically centers on removal or fusion of involved articulations, and the complex structure of the wrist requires a thorough understanding of anatomy and kinematics to select an appropriate treatment for each patient.

Main Text

Wrist Anatomy

The intricate articulation of the osseous structures of the wrist with ligamentous support allows for multiple directions of motion. The combination of intercarpal, radiocarpal, and distal radioulnar joint motions provides multiple degrees of motion: flexion/extension, radial/ulnar deviation, and pronation/supination. The surrounding ligaments of the wrist provide the stability necessary for this wide range of motion [7]. Fractures or ligamentous injury can alter the normal mechanics of motion of these articulations, resulting in abnormal joint loading and subsequent osteoarthritis. This may occur in predictable patterns allowing treatment to be tailored to each patient's stage of arthritic change. Understanding the specific anatomy of the wrist is paramount to understanding these patterns of degeneration.

Carpus and Intercarpal Joints

The carpal bones are customarily described in two carpal rows: proximal and distal. The proximal row consists of, from radial to ulnar, the scaphoid, lunate, triquetrum, and pisiform (Fig. 6.1). This group of carpal bones is also termed the intercalary segment as there are no extrinsic ligamentous connections directly to these structures. The movement of the proximal carpal row is based entirely on their

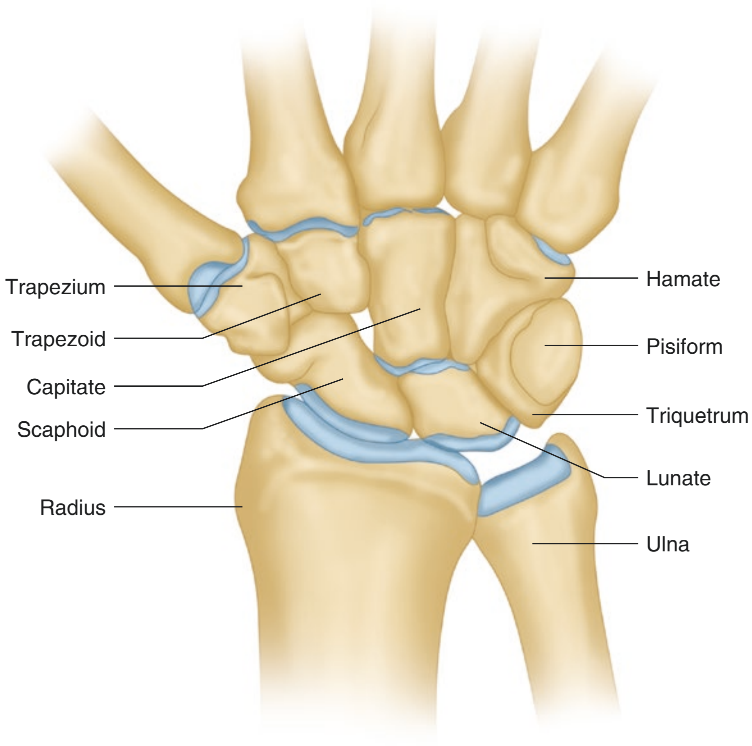

Fig. 6.1 Illustration: Carpus. Proximal row: Scaphoid, lunate, triquetrum, pisiform. Distal row: trapezium, trapezoid, capitate and hamate

articulations with the distal carpal row and the radius and ulna as well as their ligamentous supports [6].

Ligaments of the wrist include palmar and dorsal radiocarpal, ulnocarpal, intercarpal, palmar midcarpal, proximal and distal interosseous, and distal radioulnar ligaments [7]. The proximal interosseous ligaments, the scapholunate and lunotriquetral, provide interconnection between the bones of the proximal carpal row allowing coordinated movement. These interosseous ligaments each contain proximal, volar, and dorsal components with the dorsal aspect of the scapholunate interosseous ligament (SLIL) and the volar component of the lunotriquetral interosseous ligament (LTIL) providing the strongest support for their respective joints [7, 9]. Injury to these ligaments results in atypical patterns of movement between the bones within the carpal row, termed carpal instability dissociative (CID) [3, 6, 8, 9]. The distal carpal row includes, from radial to ulnar, the trapezium, trapezoid, capitate, and hamate (Fig. 6.1). Gelberman reviewed the ring concept of the carpal rows highlighting the interconnected kinematics based on the scaphoid as a stabilizing link between rows and the triquetrum as a pivot point for carpal motion [3]. With radial deviation of the wrist, the distal row moves radially and forces the scaphoid

Fig. 6.2 Lateral radiograph of the wrist showing a normal radiolunate angle of zero degrees

and the entire proximal row into flexion to avoid direct impact. The scaphoid rests in a position of slight flexion with a normal radiographic scapholunate angle of less than 70 degrees [6] (Fig. 6.2). The lunate rests in a neutral position, hence the normal radiolunate angle of zero (Fig. 6.2).

Distal Radioulnar Joint

The distal aspects of the radius and ulna form the distal radioulnar joint (DRUJ) that allows the forearm to rotate in pronation and supination in coordination with the proximal radioulnar joint at the elbow. The sigmoid notch of the radius provides a concavity in which the ulna articulates. The surrounding soft tissue structures provide not only stability for the DRUJ but also prevent impingement at the ulnocarpal

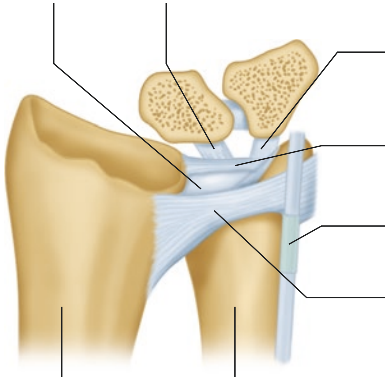

Fig. 6.3 Illustration: Structure of the TFCC

joint. The triangular fibrocartilage complex (TFCC) is composed of fibrocartilage, ligament, and joint capsule and separates the DRUJ from the radiocarpal joint [7]. The TFCC includes the dorsal and palmar radioulnar ligaments, the ECU subsheath, the ulnocarpal ligaments and the triangular articular disc that lies between the dorsal and palmar ligaments [7] (Fig. 6.3).

Wrist Arthritis

Evaluation

Diagnosis of posttraumatic arthritis of the wrist requires a history of trauma; however this is often remote or vague. Tenderness on physical examination is an important clue to the location of injury or arthritis; although, anesthetic and/or cortisone injections may be helpful in localizing pain generators [4]. The scapholunate interval, radial border of the scaphoid, and scaphotrapeziotrapezoidal (STT) joint are important landmarks for palpation although the entirety of the wrist, including all intercarpal joints, should be systematically examined [5, 13]. Dorsal wrist swelling and/or a joint effusion may be present [13]. Pain may be elicited with wrist extension and radial deviation, which loads the radial side of the wrist [9]. Dynamic tests such as the scaphoid shift test should be included in the exam [5, 9]. In this test, scapholunate dissociation may be diagnosed through dorsal subluxation of the scaphoid with palmar-dorsal pressure on the tuberosity during radial deviation causing pain. A clunk will occur as the scaphoid reduces into position with radial deviation and/or removal of pressure [3, 9]. Radiographs are necessary in initial evaluation and should be scrutinized for signs of altered carpal alignment, joint space loss, osteophyte formation, loose bodies, and subchondral sclerosis or cystic change [3, 4, 13]. Standard posteroanterior and lateral views should be obtained in addition to an ulnar-deviated clenched fist, or "scaphoid," view and a 45-degree pronation view [5]. Ulnar variance can only be appropriately assessed with the forearm in neutral rotation, the elbow flexed 90 degrees, and the shoulder at 90 degrees of abduction [5]. The pencil grip view may also demonstrate an increase in ulnar variance as compared to a neutral, non-grip view. Advanced imaging is rarely required for diagnosis; although, magnetic resonance imaging (MRI) may be useful in evaluating the status of articular cartilage [4].

In general, nonsurgical options for management of arthritis of the wrist include immobilization with braces or splints, nonsteroidal antiinflammatory medications (NSAIDs) if tolerated, and selective cortisone injections; although, they often provide only temporary relief. These options should be exhausted prior to surgical intervention [4]. The goals of surgical treatment are to eliminate pain, improve function, and prevent further damage, if possible [4].

Intercarpal and Radiocarpal Arthritis

In contrast to normal kinematics, with carpal ring disruption the bones of the wrist move in a discordant fashion [3]. Injuries causing disruption of the carpal ring may be isolated intercarpal ligament injuries, SLIL injury associated with a distal radius fracture, or multiple intercarpal ligament injuries associated with perilunate instability or dislocation [3, 9]. When associated with an extrinsic cause the resulting deformity is termed carpal instability adaptive (CIA) [3, 6, 9]. When chronic in nature, these injuries may lead to intercarpal and radiocarpal joint degeneration.

Scapholunate Advanced Collapse (SLAC) and Scaphoid Nonunion Advanced Collapse (SNAC)

Chronic SLIL injuries causing carpal instability may lead to subsequent radiocarpal and intercarpal arthritis although the natural history of SL ligament injuries is not well documented [7, 13]. In the pathologic state where the SLIL is compromised, the scaphoid will flex while the lunate will independently fall into extension leading to dorsal angulation of the lunate relative to the radius on a lateral radiographic view, termed dorsal intercalated segment instability (DISI) [3, 5, 6, 9, 13, 15] (Fig. 6.4). As this process progresses the capitate may migrate proximally as well [5]. There are no studies confirming that SL ligament tears, diagnosed with direct visualization through arthroscopy, inevitably lead to arthritis [13]. When degenerative changes do occur, radiographically, they will follow a predictable pattern termed scapholunate advanced collapse, or SLAC, wrist [4, 10, 11]. First described by Watson and Ballet based on their review of 4000 radiographs, of which 210 showed degenerative wrist arthritis, SLAC wrist was the most common pattern affecting 57% of those patients [10]. Initially, changes are noted at the tip of the radial styloid and the distal scaphoid (stage I), followed by involvement of the entire radioscaphoid joint (stage II) (Fig. 6.5). These specific changes result from the

Fig. 6.4 Lateral radiograph demonstrating dorsal intercalated segment instability (DISI) deformity

incongruent geometry of the scaphoid with the radius when the scaphoid falls persistently into flexion [5, 12]. The capitolunate joint is the first midcarpal joint involved (stage III) (Fig. 6.6), and the final stages may include the rest of the carpus although the radiolunate joint is characteristically uninvolved [2, 3, 5, 10–12]. This is thought to be from the highly congruent nature of the lunate in the fossa of the distal radius [10]. It is important to note that patients with a SLAC wrist pattern may be asymptomatic. Further, atraumatic causes such as calcium pyrophosphate deposition must be considered [2, 13]. Radiographs of the contralateral wrist in an asymptomatic patient may also show SLAC changes [13].

Less commonly, nonunion of the scaphoid may lead to a scaphoid nonunion advanced collapse (SNAC) wrist deformity [12, 13] (Fig. 6.7). The SNAC pattern is similar to a SLAC wrist with the anatomic difference being the maintained

Fig. 6.5 PA radiograph: Stage II SLAC wrist

attachment of the proximal pole of the scaphoid to the lunate via the SLIL and, thus, an arthritis-free articulation between the proximal pole of the scaphoid and the radius [3, 5, 11, 12, 15]. Two reports on the natural history of scaphoid nonunions were published in the 1980s [14, 15]. Mack et al. evaluated 47 scaphoid fractures with a range of five to 53 years of known nonunion and identified three patterns of degeneration. At an average of 8.2 years, patients developed isolated scaphoid sclerosis and cystic changes. By 17.0 years, radioscaphoid arthritis developed, and at an average of 31.6 years generalized arthritis of the wrist developed. Overall they concluded that by 10 years all nonunions were displaced, unstable, or arthritic, and by 20 years, generalized arthritis of the wrist was common. Ruby et al. reviewed their series of 56 scaphoid nonunions and noted a 97% rate of osteoarthritis at 5 years or greater after injury [15]. These population studies suggest that osteoarthritis is likely to develop in patients with an established scaphoid nonunion, particularly those that are displaced, and thus scaphoid fixation is often recommended for nonunion even in asymptomatic patients, to prevent future degenerative change.

Fig. 6.6 PA radiograph: Stage III SLAC wrist

Management

Nonoperative options are the mainstay of initial treatment although there are no long-term studies evaluating these methods specifically in SLAC/SNAC deformities [4, 13]. As discussed previously, bracing, directed injections, and anti-inflammatory medications may be used in appropriate patients for symptomatic management. Symptoms refractory to conservative management or severe symptoms on presentation warrant consideration of surgical intervention.

Surgical management of SLAC and SNAC wrist is aimed at the stage of involvement. Prior to the development of arthritic changes, direct repair or reconstruction of the scapholunate ligament, with or without radial styloid excision, or treatment of the scaphoid nonunion may be undertaken with the goal of preventing the

Fig. 6.7 PA radiograph: SNAC wrist

development of end-stage arthritis. Once arthritic changes have occurred, treatment options change significantly [5].

Wrist arthroscopy has a limited role in management but may be useful for evaluation of cartilage surfaces to select an appropriate salvage procedure. For example, arthroscopy allows for direct visualization of the radiocapitate joint to determine if a scaphoidectomy with four-corner fusion (S4CF) is more appropriate than a proximal row carpectomy (PRC), which is contraindicated in the presence of capitolunate arthritis [2, 5]. For stage I SLAC changes, a radial styloidectomy is appropriate to improve pain although this will not inhibit progression of arthritis [5]. Key technical points include protecting the dorsal branches of the radial sensory nerve and resecting less than 3–4 mm to maintain the volar radiocarpal ligaments so as not to induce carpal instability [2, 13]. For more advanced stages of arthritis surgical options include limited wrist fusion, such as a S4CF, scaphocapitate or scaphotrapeziotrapezoidal (STT) arthrodesis, PRC, wrist denervation, total wrist arthroplasty and total wrist arthrodesis [2, 5, 13]. In contrast to total wrist arthrodesis, limited wrist fusions allow for maintenance of wrist motion through preservation of joints unaffected by arthritis [3].

Simple excision of the distal scaphoid may play a role in arthritis management after scaphoid nonunion [3, 5, 13, 16, 17]. Malerich et al. performed a distal scaphoid excision on 19 patients with radioscaphoid arthritis secondary to a scaphoid nonunion, 13 of who sustained pain relief. The procedure is not recommended if capitolunate arthritis is present but has the benefits of minimal ligamentous disruption, and no need for internal fixation or prolonged immobilization [16]. Ruch and Anastasios treated 13 patients with distal scaphoid excision after previous surgery for symptomatic nonunion [17]. At five-year follow-up, only two patients had pain with activity and reported this as mild. Mean wrist flexion and extension increased by 23 and 29 degrees, respectively. In six patients they noted a significant increase in the radiolunate angle, indicating a DISI deformity, but identified no symptomatic correlation [17].

S4CF Versus PRC

A S4CF involves complete removal of the scaphoid with fusion of the remaining capitate, lunate, hamate and the triquetrum [13]. Alternatively, a scaphoidectomy and triquetrectomy can be performed with a three-corner fusion of the capitolunate, capitohamate and hamatolunate joints. Both procedures require undamaged radiolunate articular cartilage, as this joint will remain intact [3, 12]. Correction of a DISI deformity must be performed intra-operatively prior to stabilization or radiocapitate impingement can result dorsally [2, 3, 12]. The radioscaphocapitate and long radiolunate ligament should be preserved to prevent ulnar translation of the carpus [2]. Meticulous surgical technique with preparation of fusion surfaces, removal of debris and proper hardware sizing must be emphasized [13]. Benefits of a S4CF include maintenance of carpal height, preservation of the radiolunate joint and no risk of degeneration at the radiocapitate joint [3]. Risk of nonunion and hardware complications are disadvantages of this procedure [12]. Fusion fixation may be performed with k wires, staples, headless screws or circular plates. K wire fixation is inexpensive but risks pin tract infection, sensory nerve irritation and requires removal [3, 13]. Staples and headless screws provide compression at the expense of possible dorsal impingement with staples, and technical difficulty in placing screws [3, 12]. Multiple studies have shown higher rates of nonunion and complications with circular plate fixation [3, 12, 13]. Saltzmann et al. reviewed seven studies and noted a grouped nonunion rate of seven percent after S4CF [20]. Bain and Watts evaluated clinical outcomes in 35 patients undergoing S4CF at 1, 2, and 10 years and reported pain scores of 0/10 at 1 year, and 22% loss of wrist range of motion. Between 1 and 10 years, there was no significant change in pain, wrist function, patient satisfaction, or arc of wrist motion, suggesting that results are sustainable [18]. Only two patients went on to wrist arthrodesis [18]. Some authors have advocated capitolunate fusion alone, with or without triquetral excision after scaphoidectomy, as outcomes appear similar to a four-corner fusion [2, 13, 19, 43]. In a series of 12 patients undergoing scaphoidectomy and capitolunate arthrodesis with headless compression screws alone, ten patients resumed their prior work activities and the average postoperative grip strength was 81% of the contralateral extremity [19]. The shorter operative time, rapid rate of fusion, preservation of lunotriquetral motion and early rehabilitation are reported benefits of the procedure [19].

Proximal row carpectomy involves resection of the scaphoid, lunate and triquetrum (Fig. 6.8). A new articulation between the capitate and radius is created which requires ensuring that the capitate has intact cartilage proximally prior to committing to this procedure, although there is no data providing guidance on exactly how much cartilage is necessary for a PRC to be successful [2, 3, 12]. Future degeneration of this joint continues to be a risk of PRC particularly in younger patients although it is not clear that these radiographic changes are consistently symptomatic [3, 21]. Pain relief from degeneration of the capitate in the setting of PRC has been obtained with osteochondral resurfacing or interposition procedures however no improvement in range of motion or grip strength is achieved [13]. Preservation of the radioscaphocapitate ligament is necessary to prevent ulnar translation of the capitate off the radius [3]. The benefits of a PRC include a lack of prolonged

Fig. 6.8 PA radiograph after proximal row carpectomy

postoperative immobilization, no risk of nonunion or hardware complications, technical ease, greater maintenance of wrist motion and simple conversion to a total wrist arthrodesis or arthroplasty as a salvage option [2, 3, 12, 13, 21].

Multiple studies have examined these two interventions, although randomized controlled trials are limited [5, 44]. In their systematic review, Mulford et al. caution that the current literature lacks unbiased trials and thus interpretation must be made in this context [21]. Both motion-preserving options, S4CF and PRC remain similar in outcomes for SLAC wrist in short-term follow up [13]. Cohen and Kozin performed a cohort study comparing two similar groups, each undergoing either S4CF or PRC at two separate institutions. Pain relief, function, physical score on the SF-36 and patient satisfaction were similar between groups. Greater radial deviation was maintained in the S4CF group [13]. Similar results were noted in a small review of seven studies examining short and medium term outcomes after PRC or 4CF [20]. Grip strength and radial deviation were greater after S4CF while wrist extension and flexion were greater after PRC [20]. In a systematic review of 52 studies examining patients with SLAC or SNAC wrist undergoing either PRC or S4CF, grip strength averaged 70% after PRC and 75% after 4CF. A majority of studies showed a loss of motion after either procedure. Subjective outcomes were "good" 84% of the time after PRC and 85% of the time after 4CF [21]. Grip strength after both is typically reported at 75–80% of the contralateral extremity with a 40–60 degree arc of motion after S4CF and a 60-degree arc of motion after PRC [3]. Kiebhafer recommended PRC for older and less active patients and S4CF in higher demand patients or those less than 35 years old [12]. In general, the procedures are considered equivalent for pain relief, subjective outcomes, grip strength and need for conversion to arthrodesis, in appropriately staged patients [21, 45]. A recent cost-utility analysis identified both S4CF with screw fixation specifically, and PRC as cost effective treatments for management of SLAC/SNAC wrist [46]. The method of fixation in a 4CF alters the cost effectiveness of the intervention, with plate and staple fixation reported as more costly than compression screw fixation [47].

Wrist Denervation

A relatively simple procedure for management of wrist arthritis, denervation remains an option that avoids use of hardware and allows for future salvage options if necessary [13]. Weinstein and Berger reviewed 19 patients undergoing AIN and PIN neurectomies with 2.5 year follow up [22]. Eighty percent of patients reported decreased pain and only two patients went on to arthrodesis with no complications in the group. Overall, 90% of patients would have selected denervation again for their chronic wrist pain [22]. An isolated PIN neurectomy has also been described with 90% of patients satisfied with the procedure [48]. These technically simple procedures can be used as a temporizing measure to delay salvage procedures. Often performed in Europe, complete wrist denervation is an alternative and more extensive option for management of chronic wrist pain. Originally described by Wilhelm, complete wrist denervation involves severance of branches of the PIN, AIN, palmar cutaneous nerve, sensory branch of the radial nerve, dorsal branch of the ulnar nerve, lateral and medial antebrachial cutaneous nerves and requires five incisions around the wrist [23]. Simon et al. retrospectively reviewed 27 patients undergoing complete wrist denervation by one surgeon. Forty-four percent of patients had complete relief of pain that remained stable in 89%. Grip strength was maintained at 85% of the contralateral arm. Six complications occurred including one case of complex regional pain syndrome and five neuromas with two patients requiring reoperation. Overall 67% of patients were very satisfied [24]. In a longer-term review of 30 complete wrist denervations with average 10 year follow up, 28 patients had improved pain with 22 maintaining this effect through final follow up. Grip strength was reported at 82% of the contralateral extremity [25]. In another review of 71 complete wrist denervations, 22 wrists had complete pain relief and 40 wrists had considerable improvement. Nine patients required reoperation for insufficient pain relief [26]. A more recent study of 39 wrists undergoing total wrist denervation with an average 56 months follow up resulted in pain improvement in 79.5% of cases with four revision procedures and four complications [49]. Complete wrist denervation may provide and maintain sufficient pain relief without sacrificing grip strength or future salvage procedures.

Total Wrist Arthroplasty and Arthrodesis

Severe arthritis of the radiocarpal joint or pancarpal arthritis requires total wrist arthroplasty or arthrodesis [3] (Fig. 6.9). Total wrist arthroplasty removes painful arthritic surfaces and replaces them with a prosthetic option. Early designs included synovitis-inducing silicone implants and unstable prostheses [3]. Newer designs have improved component fixation [3]. Arthroplasty preserves motion when compared to arthrodesis but requires a lifelong lifting restriction, usually of ten pounds or less, and is preferred in low demand patients only [2, 3].

Total wrist arthrodesis is preferred in young laborers and patients who want to continue manual work [3]. Grip strength can be maintained particularly with the wrist fused in slight extension [3]. Arthrodesis is typically performed with commercially available pre-contoured dorsal plates and autogenous bone graft, with cited fusion rates of 93–100% [3, 13]. In a retrospective review of 89 patients undergoing wrist arthrodesis for posttraumatic arthritis, 98% of the 56 patients with plate fixation went on to union, while 82% of those receiving a different form of fixation achieved union [27]. The complication rate after plate fixation was 51%, with 59% of these requiring an additional procedure, while 79% of patients with a different form of fixation had a complication but only 21% of these required an additional procedure [27]. Arthrodesis is thought to be reliable for pain relief and allows patients to perform most activities of daily living through compensation of other joints [2]. Although many studies report patient satisfaction after total wrist arthrodesis, complete pain relief may be less often achieved than perceived based on these series [28]. Jupiter and Adey reported persistent pain in 64% of their series of 22 patients who underwent arthrodesis for posttraumatic arthritis, suggesting that this

Fig. 6.9 PA and lateral radiographs after total wrist arthrodesis

pain relief procedure may be less predictable than previously thought [28]. De Smet et al. compared PRC to wrist arthrodesis in a nonrandomized retrospective study of 61 patients with posttraumatic osteoarthritis of the radiocarpal joint. While there was no difference in grip strength between groups, functional outcome scores, maintenance of professional activity and complication rates were better in the PRC group [29]. Additional sources of pain must be considered when opting for wrist arthrodesis and should be addressed.

Surgical Technique

A dorsal approach is typically preferred for most salvage procedures. Dissection through the third dorsal compartment with radial transposition of the extensor pollicis longus (EPL) is followed by a longitudinal, step cut or transverse ligament-sparing incision through the dorsal wrist capsule [3]. Lister's tubercle is easily identified in the surgical field and can be removed to obtain distal radius bone graft. For some implants removal of this tubercle allows greater flexibility of plate position and less hardware prominence [3]. Weiss and Rodner recommend a surgical technique that maintains precise capsular incisions to facilitate closure, avoids ligaments of the wrist that are not involved to prevent secondary instability, and uses transverse incisions when possible to preserve motion. Dissection must be performed carefully to protect the sensory branches of radial and ulnar nerves, and excision of the PIN may assist with denervation of the wrist and pain control. Use of autogenous bone graft, preferably from the distal radius or iliac crest, as opposed to resected carpal bone, is recommended [3].

Isolated Radiocarpal Arthritis

Radiocarpal arthritis in the absence of intercarpal arthritis may result after an intra-articular or malunited distal radius fracture [3, 6, 9]. Intra-articular step-off or loss of normal volar tilt, radial height or inclination with malunion may alter points of contact and load leading to degenerative changes.

Management

Radioscapholunate (RSL) arthrodesis may be performed for pain relief at the expense of wrist motion, which is typically 33% of normal. Concomitant excision of the distal scaphoid may increase range of motion to 50–60% of normal [3]. Proponents of scaphoidectomy have postulated that inclusion of the entire scaphoid in an RSL arthrodesis leads to degeneration of the STT joint as the distal row is unable to flex over the proximal row [30]. Garcia-Elias reviewed 15 cases of RSL arthrodesis with distal scaphoidectomy for posttraumatic arthritis from distal radius fractures (13 patients) or perilunate fracture-dislocations (two patients). The midcarpal joints were uninvolved in all patients. Complete pain relief was achieved in ten patients and overall pain relief was noted to be greater than that reported in their previous series of 27 patients who did not have a concomitant distal scaphoidectomy [30]. In comparing their outcomes to the literature on RSL arthrodesis alone, they note greater motion in wrist flexion and radial deviation with distal scaphoidectomy [30].

Isolated Intercarpal Arthritis

Scaphotrapeziotrapezoidal Arthritis

STT arthritis may cause radial-sided wrist pain. The posttraumatic nature of STT arthritis is unclear. While it has been suggested that an isolated SL ligament rupture, without instability or rotatory subluxation of the scaphoid, may cause degeneration of the STT joint, this may be a reflection of the prevalence of STT arthritis as opposed to confirmation that trauma is a common etiology of degeneration at this joint [5].

Management

Management options for STT arthritis include joint debridement, distal scaphoidectomy (open or arthroscopic), trapeziectomy, partial trapezoid resection, STT arthrodesis or arthroplasty [5, 50, 51]. Excisional arthroplasty can be performed for STT arthritis when not associated with dorsal midcarpal instability as distal scaphoid resection could cause collapse into DISI [31]. This technique is technically simple with few complications and does not require prolonged immobilization [31]. Arthrodesis of the STT joint has been extensively although reports often include patients with Kienbock's disease in addition to traumatic etiologies [32]. Radial styloidectomy should be performed at the time of fusion, with postoperative motion expected to be approximately 65% of normal [4]. In a review of multiple studies reporting on a total 238 patients, the average nonunion rate was 13%. The grouped complication rate was 43% and included pin track infection, progressive arthrosis, nerve irritation and osteomyelitis, amongst others [33]. Forty-nine percent of patients reported persistent wrist pain [33]. Alternatively, Pequinot reported a small series of patients undergoing pyrocarbon STT replacements citing a pain relief procedure that preserves carpal stability, has a low complication rate and does not preclude salvage with fusion. Patients had a slight loss of pinch strength and wrist motion with 10 degrees less radial deviation and 15 degrees less wrist extension while grip strength was maintained at 4 year follow up [34].

Lunotriquetral Arthritis

Injury to the LTIL is significantly more rare than SLIL injury and typically occurs from a fall onto an outstretched, supinated and extended wrist [2, 5]. Force transfers from the pisiform into the triquetrum while the lunate remains tethered by the long radiolunate ligament. The contradictory forces lead to rupture of the intervening ligament [2]. These injuries may also occur as part of a perilunate dislocation (stage III). An intact SLIL in the setting of an LTIL rupture will flex the lunate with the scaphoid resulting in a volar intercalated segment instability (VISI) deformity [2, 5, 6, 9]. Ligament rupture with subsequent VISI deformity is not, however, clearly correlated with development of arthritis. In a biomechnical study of ulnar column instability from LTIL tears, cadaveric wrists were loaded in 12 different positions with a pressure sensor film measuring load across the radiocarpal joint in each stage of perilunate injury. No significant differences in pressure were noted in any stage suggesting that a VISI deformity does not necessarily correlate with clinical development of arthritis [35].

Management

After attempting nonoperative interventions, management of lunotriquetral arthritis after an LTIL injury is often with lunotriquetral (LT) fusion. Isolated LT arthrodesis will not improve a static VISI deformity and thus Peterson recommends including the hamate in the fusion or performing a 4CF to correct VISI [5]. Positive ulnar variance must also be corrected with shortening or resection at the time of LT fusion [5]. Kirschenbaum reviewed a series of 14 patients undergoing LT arthrodesis for chronic LT instability. Twelve patients went onto fusion and one pseudarthrosis required a second procedure but healed. Wrist motion ranged from 80% to 88% of the contralateral arm depending on direction of motion tested and grip strength averaged 93% comparatively [36]. LT fusion remains a pain relief operation with reasonable maintenance of motion and grip strength, at least in the short-term [36]. Despite wide use of this procedure, a comparison study of arthrodesis, direct ligament repair and ligament reconstruction reported that the probability of remaining free from a complication at 5 years was less than one percent in the arthrodesis group. This compared to 68.6% and 13.5% for the reconstruction and repair groups, respectively. Results followed the same trend for probability of not requiring further surgery. While DASH scores did not differ, objective measurements and subjective satisfaction scores were significantly higher in the repair and reconstruction groups compared to the arthrodesis group [37]. This study suggests that LT fusion may not be the ideal intervention for degenerative changes due to LTIL injury.

Pisotriquetral Arthritis

This uncommon location of arthritis, when it occurs, is often posttraumatic in nature and may result from acute or chronic injuries [4, 5]. Diagnosis may be suggested by tenderness with loading of the pisotriquetral joint and can be confirmed with a directed injection. A supinated oblique radiographic view allows direct examination of the pisotriquetral joint [5]. Ulnar nerve symptoms or rupture of the small finger flexor profundus are possible with arthritis of this joint, due to the proximity of these structures [5].

Management

As with other forms of arthritis, management with splinting, nonsteroidal antiinflammatory medications or injections, is attempted initially [5]. Simple pisiformectomy with care to preserve the flexor carpi ulnaris insertion is the surgical treatment of choice for cases that do not respond to nonoperative measures [4, 5].

Distal Radioulnar Joint and Ulnocarpal Arthritis

Arthritis of the DRUJ or ulnocarpal joint can have one of many traumatic causes. A fracture of the distal radius with malunion may result in shortening that alters the relative length of the ulna. Normally carrying approximately 20% of the load on the forearm, the ulna is then overloaded inappropriately and ulnocarpal arthritis may result [3, 4]. Furthermore, the relationship of the distal ulnar articulation with the sigmoid notch of the radius may be changed predisposing to DRUJ arthritis [4, 38]. Alternatively, a soft tissue injury such as an injury to the TFCC, which includes the stabilizing ligaments of the DRUJ, can also contribute to the development of post-traumatic arthritis of the DRUJ and/or ulnocarpal joints [4].

Management

Treatment of ulnocarpal arthritis requires offloading the distal ulna. This can be achieved through height restoration with a radial osteotomy, ulnar shortening, wafer procedure or a distal ulnar resection, known as a Darrach procedure.

Arthritis of the DRUJ may be managed with partial or complete distal ulnar resection, hemiresection interposition (HIT) arthroplasty, endoprosthetic replacement or arthrodesis of the DRUJ with pseudarthrosis of the distal ulna, known as the Sauve-Kapandji (SK) procedure [4, 38, 41, 52]. Procedures that maintain the TFCC and ulnar styloid have the benefit of preventing ulnocarpal impingement [4].

Bowers performed a DRUJ HIT arthroplasty in 38 patients with the goal of preserving the ulnocarpal ligament complex. At 2.5 year follow up, 100% of the patients with a traumatic etiology of arthritis had painless range of motion with an average 83 degrees of pronation to 83 degrees of supination and no instability [39]. Nawijn et al. reported higher satisfaction scores in patients undergoing HIT arthroplasty for inflammatory compared to posttraumatic DRUJ arthritis [53]. Santos et al. reported on three patients undergoing DRUJ arthroplasty, two of who had posttraumatic DRUJ arthritis. In the short term, both patients achieved pain relief and had increased motion at the DRUJ [41]. Watson performed a matched ulnar resection in 44 patients, in which a convex resection of the distal ulna is undertaken to match the concave shape of the distal radius with maintenance of the TFCC and ulnocarpal ligaments [40]. Patients were followed for an average 6.5 years and maintained 80.5 degrees of painless pronation and 88.5 degrees of supination [40]. Endoprosthetic replacement with a semiconstrained DRUJ arthroplasty has been utilized in the management of DRUJ arthritis with early reports citing low complication rates and a more recent review reporting further surgery secondary to complications in 29% of patients [54]. Commonly cited soft tissue complications may be more frequent in patients with a history of rheumatoid arthritis or immunosuppression compared to those without [55].

The SK and Darrach procedures are often applicable in similar clinical situations, each with their benefits and complications. The Darrach procedure may be complicated by ulnar translation of the carpus and/or distal ulnar stump instability [4, 40, 41]. The SK procedure may be complicated by a persistently painful pseudarthrosis [40]. Studies on these procedures have been primarily in rheumatoid populations. George et al. published one of the only reports on the use of these procedures in a posttraumatic setting [42]. They retrospectively reviewed the use of the SK or Darrach procedures in patients under age 50 with DRUJ arthrosis after distal radius fracture malunion. Twelve patients after an SK, and 21 patients after a Darrach were included. At final clinical follow up there were no significant differences in subjective pain or functional scores, forearm or wrist rotation, or complication rates between the two groups. One patient required conversion to a Darrach after initial treatment with an SK [42]. The procedures are considered equivalent for treatment of posttraumatic DRUJ arthritis in this group [42]. The SK procedure has been modified to include tenodesis of the ulnar shaft with a distally based portion of the FCU tendon. In a review of 18 patients undergoing this modification, grip strength increased from 36% to 73% of the contralateral upper extremity. Sixteen patients had stable ulnar stumps and overall pain relief was satisfactory [38]. The procedure is recommended in younger patients who place high demands on their wrist or as a salvage procedure in patients with severely limited forearm rotation [38].

Summary

Arthritis of the wrist encompasses degeneration of intercarpal, radiocarpal, ulnocarpal, and distal radioulnar articulations. More common injuries include scapholunate ligament injuries leading to a well-described pattern of arthritis termed a SLAC wrist, and distal radius fractures which can predispose to radiocarpal, ulnocarpal and/or DRUJ arthritis. Evaluation of patients with wrist arthritis requires a thorough history and a physical exam centered on identification of areas of swelling and localizing tenderness on the many articulations of the wrist. Radiographs are often sufficient for diagnosis of arthritis with advanced imaging rarely necessary. Initial treatment with nonoperative interventions such as splinting, injections and NSAIDs are exhausted before surgical intervention. Operative management typically involves debridement, resection, fusion, or replacement of joint surfaces. Most of these interventions in the wrist have proven to be successful pain relief operations at the expense of wrist motion and grip strength although most patients are able to maintain adequate function.

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Chapter 7
Post-traumatic Arthritis of the Hand

Andrew P. Harris, Thomas J. Kim, and Christopher Got

Key Points
- The goal standard for interphalangeal joint arthritis is arthrodesis.
- Thumb MCP joint arthroplasty is a good option for low demand patients.
- The CMC arthritis treatment algorithm is similar to IP and MCP arthritis.

Introduction

Arthritis of the hand is a common ailment of the general population with a prevalence of approximately 20–30% [1]. Being the second most common location of pain due to osteoarthritis, it is a common condition that hand surgeons must often treat [1, 2]. The scale of the patient's debilitation varies in severity, but the most common complaints involve stiffness, limitations of daily activities, and aesthetic deformity. Unlike large joints such as the knee or hip, where artificial joint replacement has been successful for many years, the small joints of the hand have not enjoyed such long-term success to a similar degree with replacement surgery. This chapter will discuss current treatments and the available literature regarding outcomes of posttraumatic osteoarthritis of the interphalangeal joints of the fingers and thumb as well as of the metacarpophalangeal and carpometacarpal joints.

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_7

Distal Interphalangeal Arthritis

Trauma can occur commonly at the distal interphalangeal (DIP) joint as it is located at the most vulnerable distal aspect of the fingers. Fractures at the distal phalanx can occur at the tuft (distal), shaft (middle), or at the articular surface (proximal). Injuries involving the articular surface of the distal phalanx or at the head of the middle phalanx can lead to arthritis at a later time. Bony mallet finger injuries and flexor digitorum profundus avulsion injuries can also involve a significant portion of the DIP joint and can similarly accelerate arthritis.

Treatment for arthritis at the finger joints is similar in algorithm to that of the large joints. Conservative treatment is the first choice consisting of antiinflammatory medications and occupational therapy. In contrast to larger joints, immobilization may be implemented in finger and thumb osteoarthritis. This is often achieved in the thumb with 1st CMC braces. Steroid injections are also an option but due to the small volume of the joint, correctly injecting an intraarticular dose is challenging. A steroid injection can often provide temporary relief for some patients. When these conservative measures have failed, surgical treatment options can be considered, including arthrodesis or arthroplasty. The gold standard for symptomatic end-stage arthritis at this joint is an arthrodesis [3]. There are many different techniques but the principle remains the same: removal of any remaining articular surface and sclerotic bone on both sides of the joint, and creation of a stable fusion bed using hardware such as a simple Kirschner wires (K-wire) or a compression screw (Fig. 7.1).

The compression screw is usually a cannulated screw which is usually placed in retrograde fashion. After exposing the joint and preparing the joint surfaces, a K-wire is advanced antegrade from the distal phalanx. As the wire tents the skin, a stab incision is made over the wire, and the wire is advanced until it protrudes just beneath the surface of the proximal aspect of the distal phalanx. The fusion surfaces are then reduced, and the wire is advanced retrograde across the fusion surface under direct visualization into the center of the middle phalanx. Then, while the fusion surfaces are held in compression, the screw is advanced over the wire. There are two main designs of compression screw that use the concept of variable thread pitch to achieve compression when the screw is advanced. The Herbert-type compression screw has a smooth center shaft with different thread pitches at the leading and trailing ends. The other screw design is fully threaded where the pitch varies along its entire length. Both types serve the same purpose in creating a compression force across the fusion bed (Fig. 7.2). Rates of union, reported to be from 80% to 100%, are high regardless of technique (Fig. 7.3) [3, 4].

Complications from DIP arthrodesis can include nonunion, failure of hardware, fracture of the distal phalanx, and infection. Stern et al. reported a nonunion rate of 11% for DIP joint arthrodesis [5]. In the event of a symptomatic nonunion, techniques have been described to remove the screw, curette out the nonunion site, and place a cortico-cancellous graft either from the distal radius or from the iliac crest [6]. There are no large series reporting outcomes for revision arthrodesis; however, the few cases reported have achieved successful revision arthrodesis with these

Fig. 7.1 Distal interphalangeal joint fusion with a compression screw and a proximal interphalangeal joint fusion with cerclage wire and Kirschner wires (AP and lateral views)

techniques [6]. Fractures of the distal phalanx can also occur as the average anteroposterior diameter of the distal phalanx is 3.5 mm while the trailing thread diameter of a Herbert standard screw is 3.9 mm, Acutrak Mini screw is 3.6 mm, and Stryker TwinFix screw is 4.1 mm [7, 8]. This can lead to disruption of the dorsal cortex of the distal phalanx and pressure on the germinal matrix, which can cause nail deformities [9]. Thus, it is important to select a proper size screw that will fit both the middle phalanx and the distal phalanx. Herbert compression screws usually range from 2.5 mm to 3.0 mm with no smaller diameters available. Smaller screw sizes have been developed, with Acutrak Micro (Regina, Canada) providing diameters ranging from 2.0 mm to 2.4 mm.

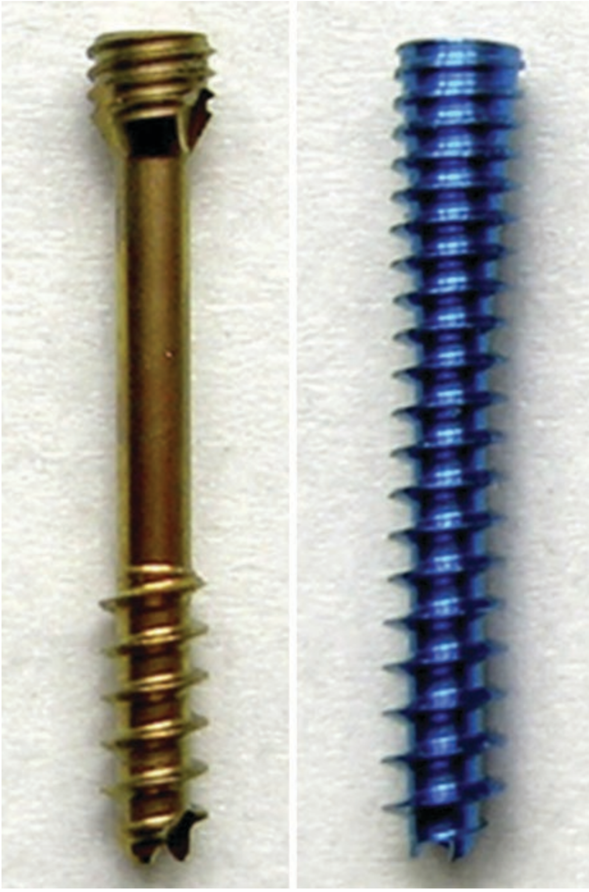

Fig. 7.2 Herbert compression screw versus fully threaded variable pitch screw

DIP arthroplasty is indicated in a select patient population. In musicians or other patients with a similar demand for fine dexterity at the fingertips, preserving motion at the DIP joint is preferred. In contrast, arthrodesis eliminates all motion at site of fusion and is more suitable for patients requiring increased demand such as heavy laborers. Fusion, in general, is the most reliable option for pain relief and avoids complications related to implant loosening and breakage [10]. Silicone arthroplasty has been reported to be performed for a small number of patients with varying but similar complication rates compared to arthrodesis at 1–10% [11, 3].

Proximal Interphalangeal Joint Arthritis

Proximal interphalangeal (PIP) joint injuries are notorious for the subsequent stiffness and arthritis that can occur. It is still a problem that has not yet been solved and because of this, there are many different treatment options. The anatomy of the PIP

Fig. 7.3 AP and lateral view of a thumb interphalangeal joint fusion with Kirschner wires

joint can be considered as a box with the volar plate forming the floor of the box, the collateral ligaments forming the sides, and the extensor mechanism forming the roof. At least two sides of the box must be disrupted for the box to become unstable. The joint is in a vulnerable position away from the palm but has enough of a lever arm so that when forces are applied from the fingertip, it can create significant injury.

Treatment options start with hand therapy, splinting, and antiinflammatories. Because posttraumatic arthritis and stiffness in the PIP joint involves much more than just the bony articular surface, therapy is essential. The soft tissue structures that contract respond well to serial digital casting, ultrasound, heat, and stretching [12–14]. Patient compliance is of utmost importance as it is a long and tedious process. Surgical options include arthroplasty and arthrodesis. The gold standard for symptomatic end-stage posttraumatic arthritis is arthrodesis. This is especially true for the index finger where pinch strength is desired and for manual laborers with increased demands on their hands. Other options for PIP joint arthrodesis are similar to the DIP joint with a tension band, compression screw, and plating commonly utilized (Fig. 7.4).

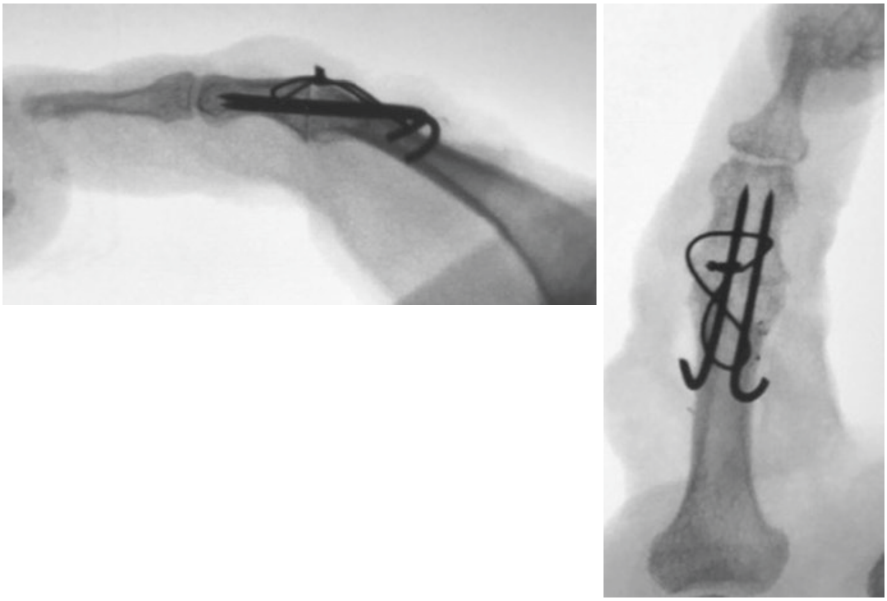

Fig. 7.4 Proximal interphalangeal joint arthrodesis with Kirschner wires and tension band (AP and lateral view)

Arthroplasty techniques include volar plate arthroplasty, silicone arthroplasty, and surface replacement arthroplasty. Volar plate arthroplasty was initially a procedure for acute fracture-dislocations of the PIP joint for which the native articular surfaces were unable to be reconstructed [15]. It has since then become a procedure that can be used for posttraumatic arthritis of the PIP joint with decent success [16, 17]. The procedure involves resection of the non-reconstructable/arthritic portions of the remaining articular surfaces and contouring those to fit one another. The volar plate is then detached distally off of the middle phalanx and transposed into the joint. Lin and colleagues performed a modified version of this procedure in seven patients with posttraumatic PIP joint arthritis. They found a decrease in pain scores and an increase in the average arc of motion by 64 degrees at a 2 year follow-up [16]. Dionysian et al. followed 17 patients for an average of 11.5 years with range of motion ranging from 30 to 110 degrees [15]. Only four patients demonstrated mild joint narrowing [15]. Silicone arthroplasty has been used to relieve pain and maintain joint motion since the 1960s [18]. They serve as spacers that allow the soft tissues to form a capsule and a pain-free stable joint. Studies have found good to excellent pain relief with no significant change in range of motion [19, 20]. Complications include implant fracture, lateral instability, silicone synovitis, and bony erosion with a reported 10–14% revision rate [21]. Because of these potential issues, there have been a number of different surface replacement arthroplasties developed.

The two most widely used joint replacements are currently the titanium-polyethylene and pyrocarbon implants. The titanium-polyethylene implants typically consist of proximal and distal titanium shafts, an alloyed proximal joint surface, and an ultra-high-molecular-weight polyethylene distal joint surface. The pyrocarbon implants consist of a radiopaque graphite core with a radiolucent pyrolitic carbon coating. This implant material has a modulus of elasticity that is similar to cortical bone. Both the titanium and pyrocarbon implants are unlinked, condylar constrained, noncemented devices. The joint stability is maintained by the joint surface geometry and the preserved collateral ligaments. A prospective randomized trial studied the differences between silicone arthroplasty, titanium arthroplasty, and pyrocarbon arthroplasty. Pain reduction and grip strength were similar in all groups. Range of motion was superior only temporarily in the titanium and pyrocarbon groups compared to the silicone group. The complications were more frequent and severe in the surface replacement groups. The titanium devices group had 27% removed and eventually replaced by silicone implants. The pyrocarbon group had 39% removed and replaced. Based on this and more recent studies that have demonstrated poor outcomes with surface replacement arthroplasty, posttraumatic arthritis is still an unsolved problem [21]. New techniques to gain stronger bone implant fixation to avoid this all too common complication of loosening with joint surface replacement are currently being investigated.

Arthrodesis is the gold standard for posttraumatic arthritis of the PIP joint. There are multiple techniques to fuse the PIP joint, including screw fixation, K-wires, tension band, and plate fixation. All three techniques are commonly used and are often dictated by surgeon preference; however, a study performed by Leibovic and Strickland demonstrated screw fixation provided the lowest nonunion rate [22]. The PIP is fused in the position of optimal function. The index and middle fingers are usually more functional in 15–30 degrees of flexion as they are used in fine pinch. The ulnar digits are more functional in 30–45 degrees of flexion as they are used in grip. Obtaining these optimal fusion angles are key to retaining maximal hand function.

Metacarpophalangeal Joint Arthritis

The hand contains five metacarpophalangeal (MCP) joints consisting of articulations with the metacarpal and first phalanx of each digit. The MCP joints are prone to trauma, especially in the setting of striking an inanimate object with a closed fist. The 2nd through 5th are the most distally based articulation when viewing a clenched hand, making them vulnerable to intraarticular damage. Crush injuries and blunt force trauma, like the other articulations of the hand, are other common mechanisms of injury.

Initial treatment of MCP posttraumatic arthritis is similar to other joints of the hand. Conservative treatment involves a multimodal approach and is generally initiated with nonsteroidal antiinflammatory medications (NSAIDS), commonly consisting of ibuprofen, celebrex, naproxen, or meloxicam. Topical treatments such as voltaren gel can be implemented. Occupational therapy or hand therapy can provide significant benefit in terms of strength and range of motion, depending on the severity of arthritis. Splinting may also be employed at the risk of increasing stiffness but providing comfort by immobilizing the affected joint. The thumb MCP joint is more amenable to maintaining function while splinted as compared to the digits 2 through 5. As with other larger articulations, the MCP joint may also undergo a trial of corticosteroid injection. Timing of injection is important because if near-future operative intervention is possible, the authors of this chapter recommend the last injection to be a minimum 3 months prior to prevent risk of infection with a maximum trial of three injections spaced at least 3 months apart [23, 24].

When conservative treatments have been exhausted, failing to provide relief and restoration of function to the affected hand, surgical options may be considered. MCP joint arthroplasty is one of the most frequently applied surgical interventions for low demand patients. Early arthroplasty designs were of the constrained hinged variety but commonly failed due to loosening or fracture [25]. Today's MCP arthroplasty components consist of either silicone or pyrocarbon. Chung et al. reported significantly improved patient reported outcomes at 1 year for patients receiving the Swanson MCP joint arthroplasty for rheumatoid arthritis [26]. In 1999, Cook et al. studied 53 predominately rheumatoid patients receiving 151 MCP pyrocarbon arthroplasties, reporting a 12% revision rate and 81.4% survival rate at 10 years [27]. Houdek et al. showed excellent results for patients with open traumatic non-reconstructable articular MCP injuries treated initially with pyrocarbon arthroplasty.

For higher demand patients or patients who have failed MCP arthroplasty, fusion of the MCP joint can be considered an initial surgical treatment or salvage procedure. Arthrodesis is effective at eliminating pain, but fusion at the correct flexion angle is necessary to provide maximum function given the limited mobility. Bicknell et al. retrospectively reviewed 27 patients that underwent thumb MCP joint fusion patients, reporting high patient satisfaction, a low complication rate, and small losses in dexterity, strength, and motion [28]. No consensus has been reached for the exact optimal position of fusion. Steiger et al. determined the optimum fusion angle of the thumb MCP to be 15 degrees of flexion and 10 degrees of pronation in contrast to a study by Saldana et al. recommending fusion for men 25 degrees and for women at 20 degrees. The angles of fusion were based on each patient's needs at the time of surgery [29, 30]. The angles of fusion of the 2nd through 5th MCP joints are generally 10, 20, 30, and 40 degrees respectively, which is the average resting positions these joints [30]. As shown by Ledgard et al., reporting improved function of patients treated with simultaneous fusion of the 2nd through 5th MCP joints for posttraumatic arthritis, the hand is able to retain excellent function if joints are fused in the appropriate position [31].

Carpometacarpal Arthritis

Carpometacarpal (CMC) joints are susceptible to trauma much like the MCP, PIP, and DIP articulations. The hand contains five CMC articulations, with the thumb CMC articulation being the most complex and important in consideration of hand function. Much like the MCP joints, the CMC joints of digits are more prone to injury and dislocation during a clenched fist strike with direct transfer of force to these articulations. The thumb CMC has two well-known intraarticular fracture pattern eponyms known as the "Rolando" and "Bennett" with the most common mechanism of axially directed force to the thumb [32]. The Rolando fracture pattern is characterized by intraarticular comminution of the 1st proximal metacarpal [33]. The Bennett fracture is characterized by a volar split of the proximal 1st metacarpal, where the volar oblique ligament inserts on the fracture fragment [34]. Aside from posttraumatic arthritis, idiopathic osteoarthritis of the thumb CMC is one of the most commonly treated conditions for practicing hand surgeons.

Even after periarticular fracture fixation of the CMC joints, posttraumatic arthritis may occur. The treatment algorithm employed is very similar to the MCP, PIP, and DIP joints. Treatment begins with conservative management, consisting of nonsteroidal antiinflammatory drugs (NSAIDS), splinting, and hand therapy or occupational therapy. Splints specifically constructed for the thumb CMC have been shown to provide significant improvement in hand function and pain relief and are often employed early in treatment. Splinting of the CMC joints 2 through 5, however, is difficult to accomplish while maintaining hand function. Corticosteroid injection is often instituted in the setting of thumb CMC arthritis but is considered a temporary solution as the duration of symptom relief has been shown to be dependent on severity of arthritis [35]. Meenagh et al., in a randomized controlled trial, showed no clinical benefit of corticosteroid injection versus placebo for patients with moderate to severe arthritis [36]. Injection of CMC joints 2 through 5 may also be attempted; although, posttraumatic arthritis to these joints is much less common than to the thumb [37].

After conservative modalities of treatment have been exhausted and pain and function have not improved to the satisfaction of the patient, surgical intervention may be warranted. Surgical options for the thumb include trapeziectomy (excisional arthroplasty) with or without suspensionplasty or ligament reconstruction, CMC fusion, and joint replacement [38, 39]. Excisional arthroplasty is considered the gold standard treatment for relatively active patients [38]. Patients who are young, healthy, or high demand and laborers may benefit from CMC fusion [39]. Low demand patients may be considered for joint replacement. Silicone thumb CMC joint replacements initially showed excellent results but were later found to be fraught with complications including synovitis, silicone wear, subluxation, cold creep, and bony erosion [38]. Early studies of pyrocarbon interpositional thumb CMC implants have shown promising results for selected low-demand patients [40]. CMC articulations 2 through 5 have relatively small amounts of motion compared to the thumb and generally respond well to fusion. However, Yong et al. have shown promising early results using the Dupert's arthroplasty technique for the 5th CMC joint, which involves resection of the base of the 5th metacarpal and fusion of the proximal shaft to the 4th metacarpal [41].

Conclusion

Posttraumatic arthritis of the hand is a common condition treated by hand surgeons. Even with proper fixation of fractures, posttraumatic arthritis may be inevitable due to the nature of the original injury. Treatment options are relative to each patient's activity demands, but, in general, conservative measures consisting of NSAIDs, immobilization, and steroid injections are trialed early on. When conservative measures have failed to alleviate discomfort and pain, surgical intervention with joint replacement, excisional arthroplasty, or arthrodesis may be warranted depending on the joints involved.

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Part III
Post-traumatic Arthritis of the Lower Extremity

Chapter 8
Post-traumatic Arthritis of the Acetabulum

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Key Points

- Articular step-off greater than 2mm significantly increases the risk of post-traumatic arthritis.
- The high failure rate of cemented acetabular components has made uncemented implants the mainstay for reconstruction in cases of posttraumatic arthritis.
- The results of THA after acetabular fracture are humbling at 10 years when compared to THA for cases unrelated to posttraumatic arthritis.
- The overall revision rates after THA following acetabular fractures are substantially higher than those following a conventional primary THA and, hence, a multispecialty treatment approach of these challenging injuries is essential.

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_8

Introduction

Acetabular fractures are challenging injuries that require careful planning and specific fixation for each fracture pattern. These injuries typically demonstrate a bimodal distribution – young patients with high-energy trauma and old patients with osteoporotic bone from low-energy falls [15]. Despite accurate open reduction and internal fixation of challenging acetabular fractures, there is an undeniable risk of developing posttraumatic arthritis that can compromise patient outcomes [19]. Certain select fracture types with significant comminution in poor bone quality require activity modification and weight-bearing restrictions as open reduction and anatomic fixation would not be successful. However, the majority of the fractures require anatomic restoration of the articular surface, especially in young patients. Elderly patients with poor bone quality may be treated conservatively allowing imperfect articular surface congruency, followed by total hip arthroplasty (THA) [20].

The incidence of posttraumatic arthritis is 13% in cases where the articular congruity has been adequately restored (less than 2 mm). There is a marked increase in posttraumatic arthritis to 44% when the step-off between acetabular articular fragments is greater than 2 mm [6]. However, the reported incidence of posttraumatic arthritis can be as high as 67% per some reports [17, 23]. Most cases of posttraumatic arthritis after acetabular fractures require THA as the mainstay of treatment. Usually, such patients can fall into one of the following three categories [12]:

- Category I – Patients with hip degeneration due to the initial injury or because of complications associated with prior treatments. Such patients may present with osteonecrosis of the femoral head, fracture mal-union, or nonunion and remnant fracture fragments.
- Category II – Comminuted fractures in elderly patients with osteoporosis that are not amenable to primary open reduction internal fixation and must rely on healing by secondary congruence. In these cases, patients can either receive a THA for an acute fracture or delayed arthroplasty for secondary congruence.
- Category III – The nature of the fracture precludes a good result with initial anatomic fixation. Impacted and multifragmentary fractures through the weight-bearing dome of the acetabulum are usually not amenable to good function even after excellent open reduction and internal fixation leading to posttraumatic arthritis.

THA remains the main treatment for posttraumatic arthritis after acetabular fractures. However, it remains inferior when compared to THA for nonfracture-related arthritis [7, 19, 21]. Increased failure in posttraumatic situations can be attributed to cemented acetabular components, initial method of fracture fixation, preexisting hardware, increased propensity for infection, younger age of the patient, abnormal anatomy, sclerotic bone bed, and decreased acetabular bone stock [15]. Conversely, cementless acetabular reconstruction has improved survivorship and has become the preferred implant choice for posttraumatic arthritis of the acetabulum [1].

In this chapter, we will outline our treatment algorithm for posttraumatic arthritis of the acetabulum including surgical planning, implant selection, and surgical technique, and we will also present some representative cases highlighting key principles. In addition, we will review current outcomes associated with THA for posttraumatic arthritis of the acetabulum.

Surgical Planning

Planning for surgery involves a thorough understanding of the patho-anatomy associated with the original fracture and possible fixation constructs used initially. A complete history and physical examination is imperative, and in acute cases, it is imperative to check the patient's soft tissue to exclude degloving injuries such as the Morel-Lavallée lesion [3]. Prior incisions must be examined to understand which approach to the hip has been previously used. Previous wounds must be examined for infections such as erythema, fluctuance, drainage, and sinus tracts. Chronic wounds with exposed bone or hardware will likely require muscle flap coverage and plastic surgeon consultation. Skin bridges between old and new incisions should be maximized in order to preserve skin blood supply.

A detailed neurovascular examination must be documented including the motor, sensory, and peripheral vascular status. Acetabular fractures may be associated with neurovascular compromise due to the mechanism of injury or subsequent surgical procedures. Nerve conduction studies, electromyography (EMG), and vascular studies may be considered preoperatively if the status is compromised. Our preference is to use the posterolateral approach to the hip which is extensile and allows adequate exposure to the acetabulum and the femur.

From the surgical perspective, we can classify the patients in to three types [20]:

- Type I – Patients requiring a conventional primary THA. In these cases, there is adequate bony support for the cup, and the hip center of rotation is preserved in its native anatomic location with no need for structural reconstruction. Such patients typically display posttraumatic arthritis in well-reduced fractures and osteonecrosis of the femoral head.
- Type II - Patients require fracture stabilization along with THA. In the majority of cases a primary THA implant would suffice, but, occasionally, there is inadequate bony support for an acetabular cup due to the unstable fracture pattern of present nonunion. Such patients will require cup support with additional internal fixation.
- Type III – Patients that require significant reconstruction; these are challenging situations due to significant alterations in the joint anatomy. With such cases, it is essential to restore the hip center of rotation with revision THA principles including bone graft or augments, cage or cup-cage constructs, and, possibly, even custom tri-flange components. Examples include cases with an absent wall, defective column, or cases with acetabular protrusio.

Radiographic evaluation begins with radiographs consisting of anteroposterior views of the pelvis and both hips along with Judet views, and inlet-outlet views of the pelvis [8]. In addition, we typically perform computed tomography (CT) scans with three-dimensional (3D) reconstruction [9, 14]. These images help with evaluating the adequacy of bony support for cup fixation at the appropriate location. We prefer classifying acetabular defects using the Paprosky classification system [16]. The images also help with evaluating the preexistent internal fixation that may or may not need to be removed to perform a THA. It is also essential to evaluate the need for supplementary fixation of walls and columns and the need for structural enhancement by bone grafts, prosthetic augments, cup-cage constructs, or custom tri-flange implants [2, 5]. This approach will help with the reconstruction of the hip center of rotation while determining adequate bony coverage of the uncemented cup over at least 80% of its outer diameter [12].

Implant Selection

The high failure rate of cemented acetabular components has made uncemented implants the mainstay for reconstruction in cases of posttraumatic arthritis [1, 5, 13]. Uncemented multihole porous metal cups allow the surgeon to plan screw trajectories in the available host bone, while the porous metal surface can achieve initial scratch fit for primary stability. Based on the type of bone defect created due to the initial injury and subsequent surgeries, it is also advisable, especially for complex reconstructions, to have various porous metal augments and cages available. Custom tri-flange components typically require 3D CT reconstructions and subsequent manufacturing from the implant company. In such cases implants should be ordered several weeks in advance.

Surgical Technique

Hypotensive anesthesia is essential to reduce blood loss in such challenging surgeries. We prefer the extensile posterolateral approach to the hip for these surgeries for excellent visualization of the acetabulum and the femur. It is important to securely fix the patient in the lateral decubitus position using either a peg board or a hip positioning device. This is because the surgeon must rely on external landmarks for appropriate cup placement, as internal structures such as the posterior wall, transverse acetabular ligament, and weight-bearing roof may not be in the native anatomic position. Intraoperative fluoroscopy must be available as well to confirm cup placement and restoration of hip center of rotation.

In cases with prior internal fixation hardware, the position of the implants may be used to locate the correct placement of the cup. We usually do not remove the previously placed implants unless they obstruct cup placement. Adequate, careful soft tissue dissection is required to visualize the acetabulum in its entirety. Release of the insertion of the gluteus maximus tendon from the linea aspera should be performed to allow the femur to be shifted anteriorly. Also, removal of the anterior capsule and scar tissue allows for a pocket to be created for the femur to be translated anteriorly. A supra-acetabular Steinmann pin or a 90-degree bent Gelpi retractor, a right angle Hohmann retractor on the posterior column, a ball-spike pusher to shift the femoral shaft anteriorly, and a blunt Hohmann retractor at the inferior border of acetabulum usually suffice for a clear 360-degree view of the socket.

Placing the cup in adequate anteversion and abduction is critical to the patient's function and implant longevity. With porous metal implants, it is essential to coat the exposed surface of the implant to avoid excessive fibrosis. While closing the incision, it is essential to not leave any dead space, and the use of drains with meticulous soft tissue closure must be ascertained. Postoperative care resembles the protocol for THA such as posterior-hip precautions and physical therapy. However, the weight-bearing status may vary depending on the stability of the reconstruction construct and it may have to be modified on an individual basis. In the next section, we will present several cases that reinforce the aforementioned principles.

Case Examples

We present case examples based on the three types of patients [20] described in the surgical planning section of the chapter:

- Type I – Patients requiring a conventional total hip arthroplasty. Figures 8.1, 8.2, and 8.3 are case examples of patients that had prior acetabular fractures which had united with sufficient bone stock for primary total hip arthroplasty without additional acetabular reconstruction.
- Type II – Patients requiring fracture stabilization along with THA. Figures 8.4, 8.5, and 8.6 are case examples of patients requiring acute fracture fixation and concurrent THA to ensure adequate support for the implants.
- Type III – Patients requiring significant acetabular reconstruction to restore the center of rotation. Figures 8.7, 8.8, and 8.9 are case examples of patients that rely upon revision hip replacement principles to ensure optimal outcome.

Outcomes

We review several studies that report on the mid-term and long-term outcomes for THA in cases of posttraumatic arthritis after acetabular fractures. A recent study from the Mayo Clinic reported their mid-term results on 30 primary THAs that were performed with a porous metal acetabular component after open reduction internal fixation (ORIF) of acetabular fractures from 1999 through 2010 [22]. From these

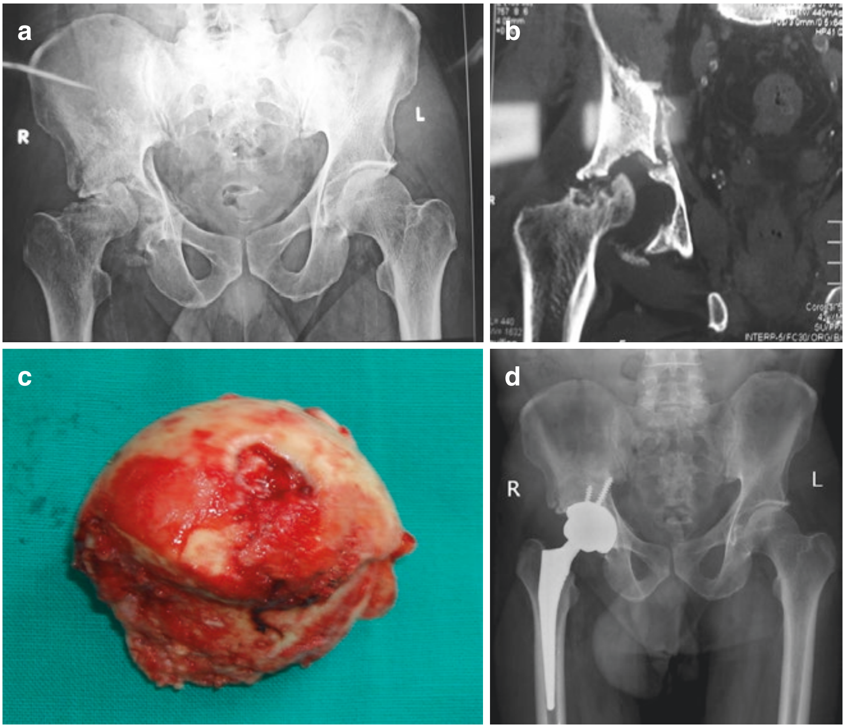
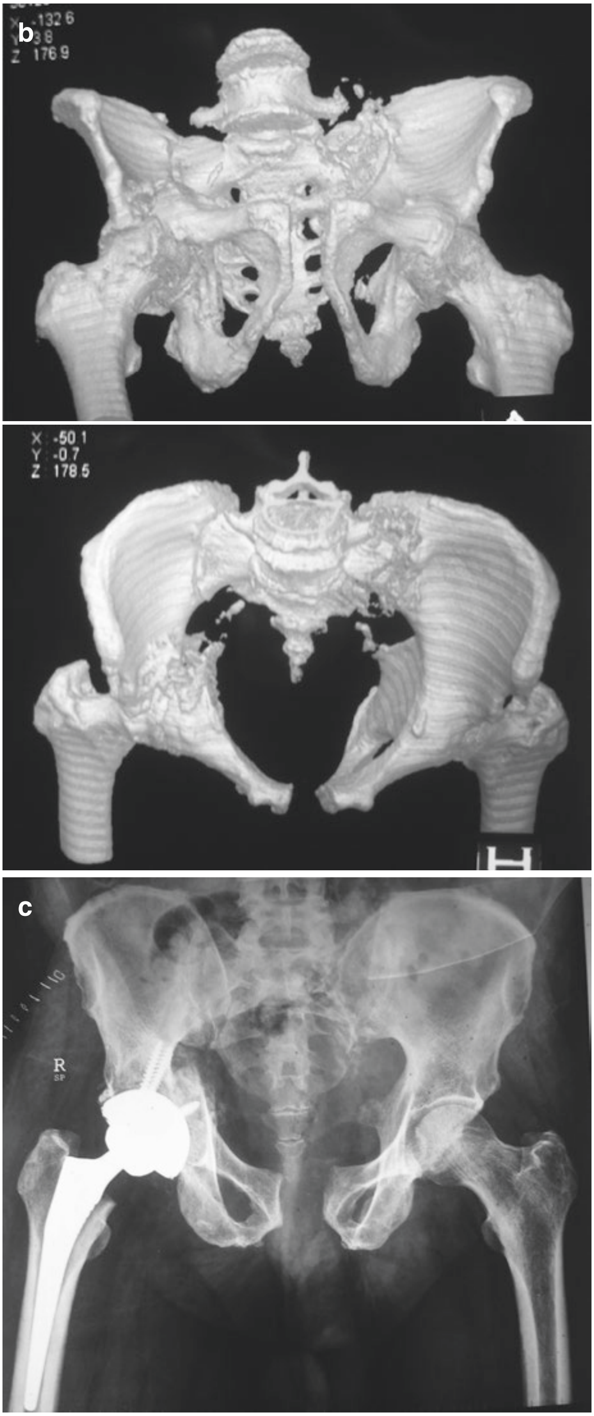


Fig. 8.1 (**a**) Pre-operative AP Pelvis radiograph of a 42 year-old male with an old acetabular fracture leading to post-traumatic arthritis secondary to femoral head osteonecrosis. (**b**) Pre-operative CT scan showing the incarcerated head fragment. (**c**) Intra-operative photograph of the incarcerated femoral head. (**d**) Post-operative AP pelvis radiograph displaying press-fit acetabular and femoral components

Fig. 8.2 (**a**) Pre-operative AP pelvis radiograph of a patient with a chronic mal-united acetabular fracture and pelvic ring injury. (**b**) 3D CT reconstructions of a patient with a chronic mal-united acetabular fracture and pelvic ring injury. (**c**) Post-operative AP pelvis radiograph displaying press-fit acetabular and femoral components

Fig. 8.2 (continued)



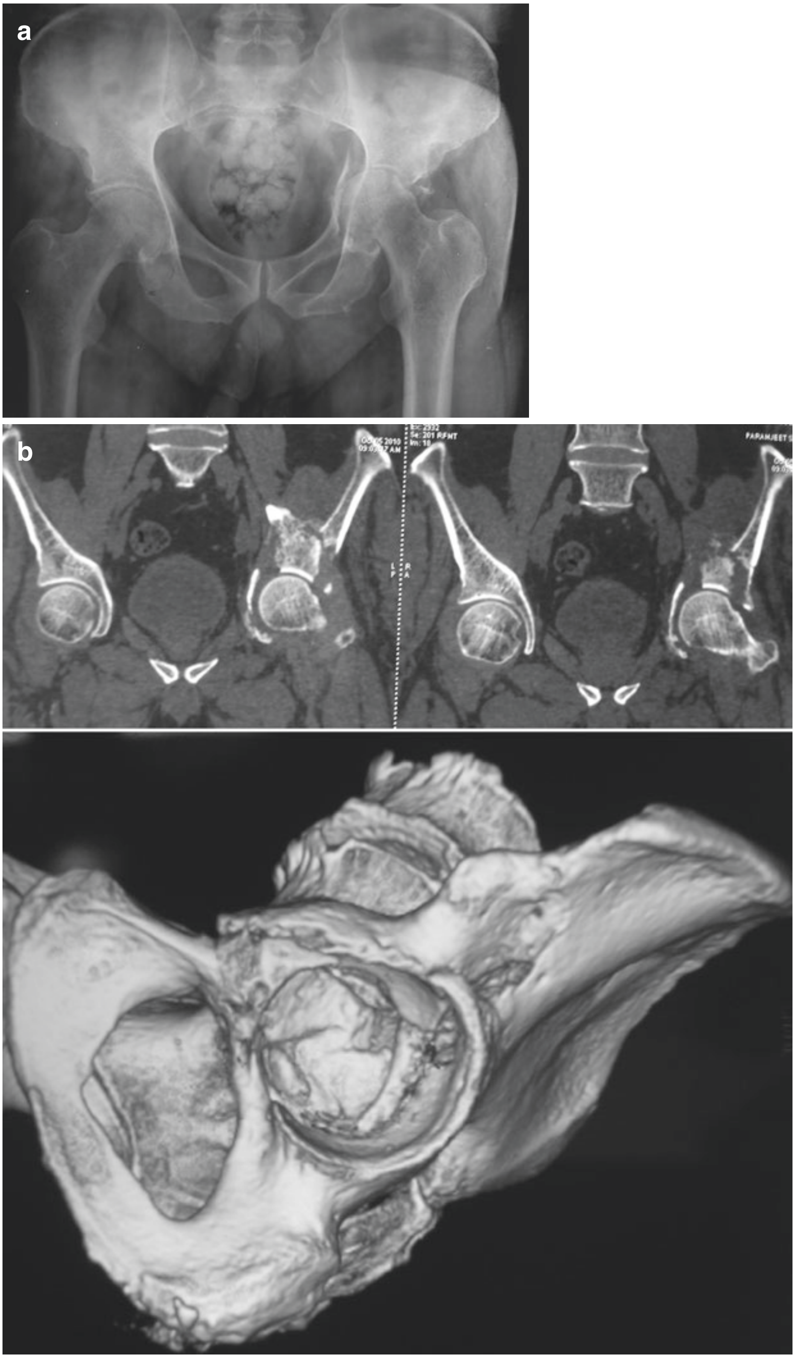


Fig. 8.3 (**a**) Pre-operative AP pelvis radiograph of a patient with a chronic acetabular fracture and medial protrusion of the femoral head. (**b**) 3D CT reconstructions of a patient with a chronic acetabular fracture and medial protrusion of the femoral head. (**c**) Post-operative AP pelvis radiograph displaying press-fit acetabular and femoral components with medial bone graft

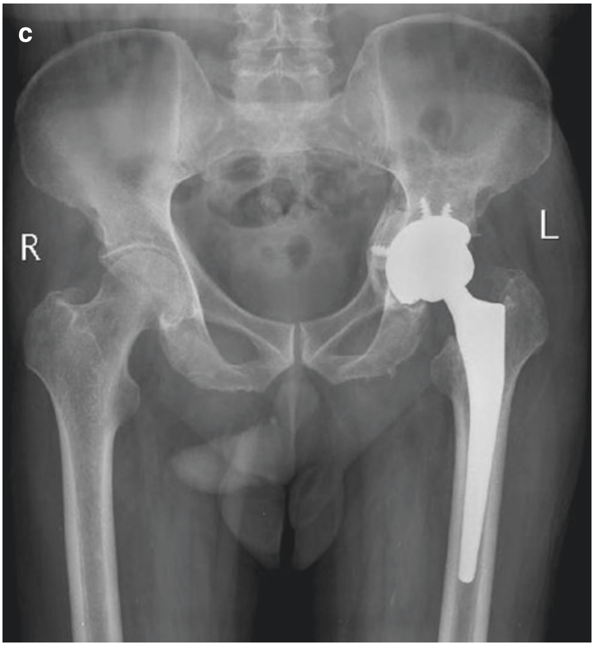


Fig. 8.3 (continued)

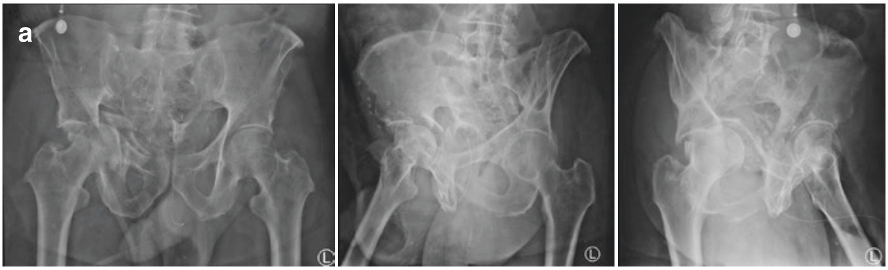


Fig. 8.4 (**a**) Pre-operative radiographs of a 67 year old patient with a both columns acetabular fracture and antecedent hip pain associated with osteoarthritis. (**b**) 3D CT reconstruction of a 67 year old patient with a both columns acetabular fracture and antecedent hip pain associated with osteoarthritis. (**c**) Post-operative AP pelvis radiograph displaying press-fit acetabular and femoral components with medial bone graft and posterior column and wall fixation

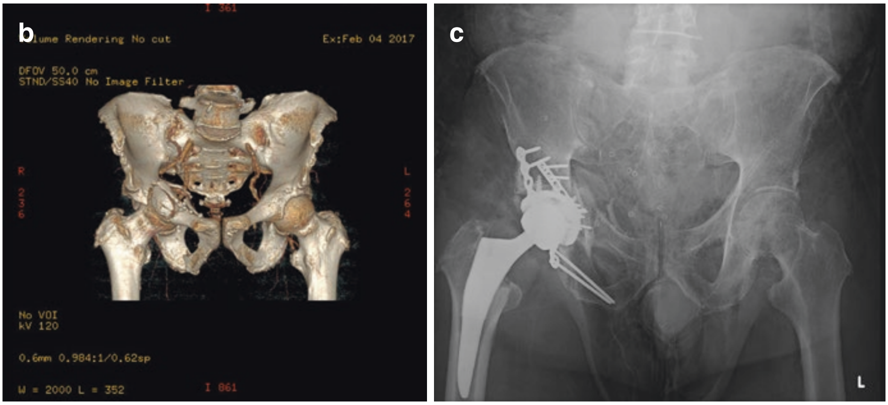


Fig. 8.4 (continued)

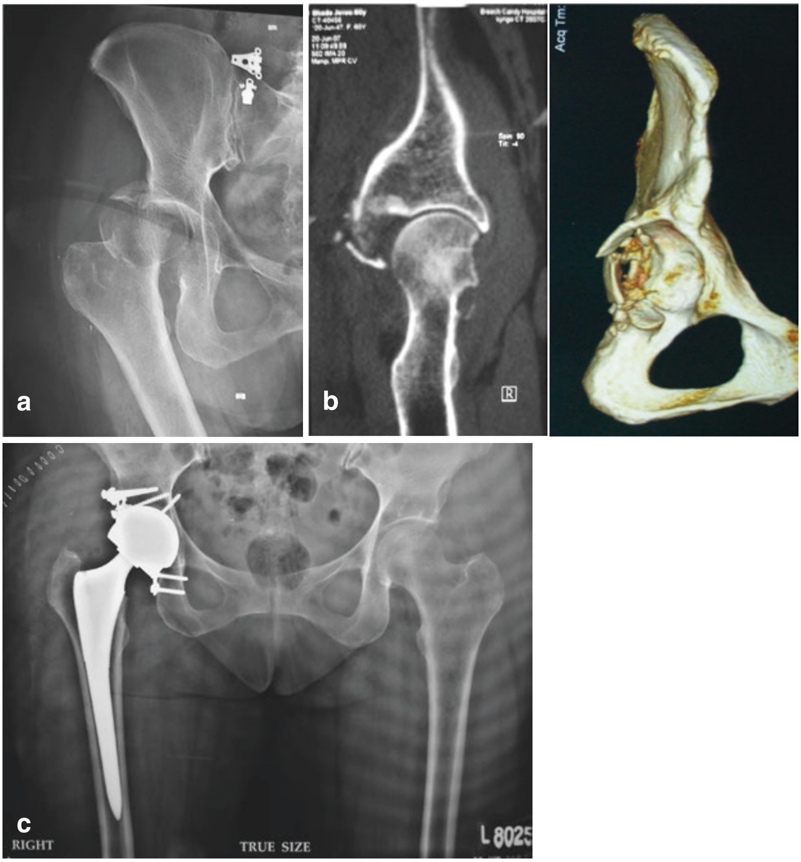


Fig. 8.5 (**a**) Pre-operative AP right hip radiograph of a 60 year-old gynecologist who sustained a fracture-dislocation of her left hip after a fall. (**b**) 3D CT reconstructions of a 60 year-old patient with the fracture dislocation. (**c**) Post-operative AP pelvis radiograph displaying press-fit acetabular and femoral components with posterior wall fixation

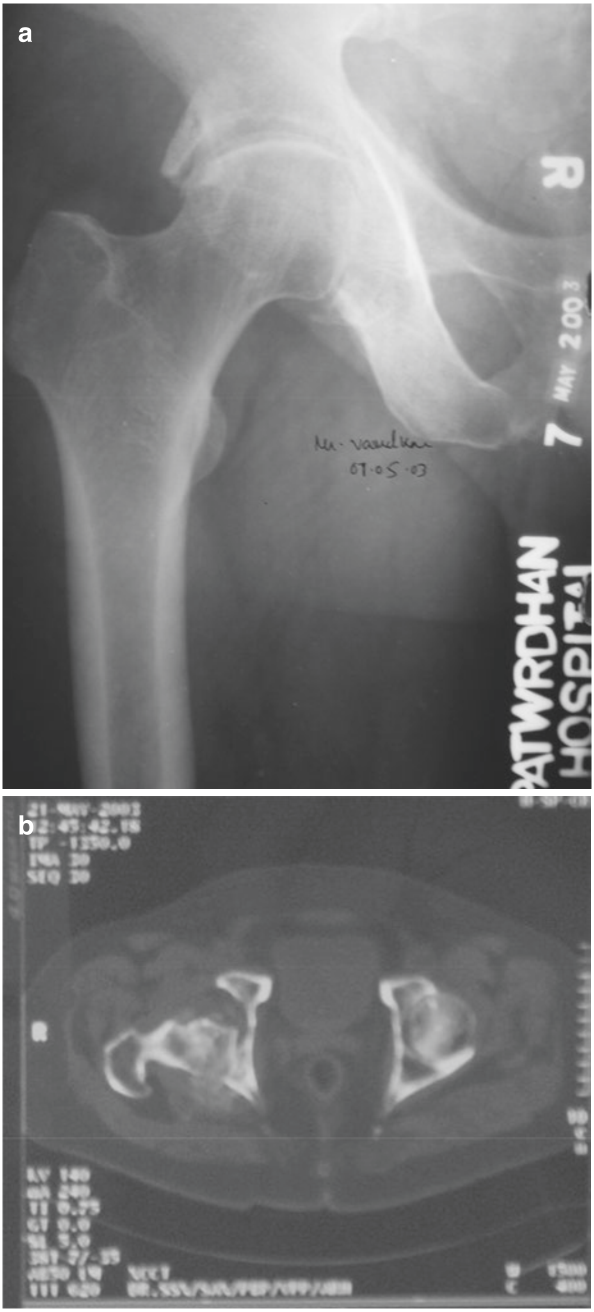


Fig. 8.6 (**a**) Pre-operative AP right hip radiograph of a 65 year-old male treated non-operatively for a right acetabular fracture. (**b**) CT reconstruction showing posterior wall erosion and femoral head subluxation. (**c**) Intra-operative pictures showing the acetabular defect and reconstruction with a segment of the femoral head fixed with inter-fragmentary screws and supported by a buttress plate, restoring the socket. A cemented hip replacement was performed. (**d**) Post-operative AP pelvis radiographs showing a cemented total hip replacement with posterior wall and column fixation

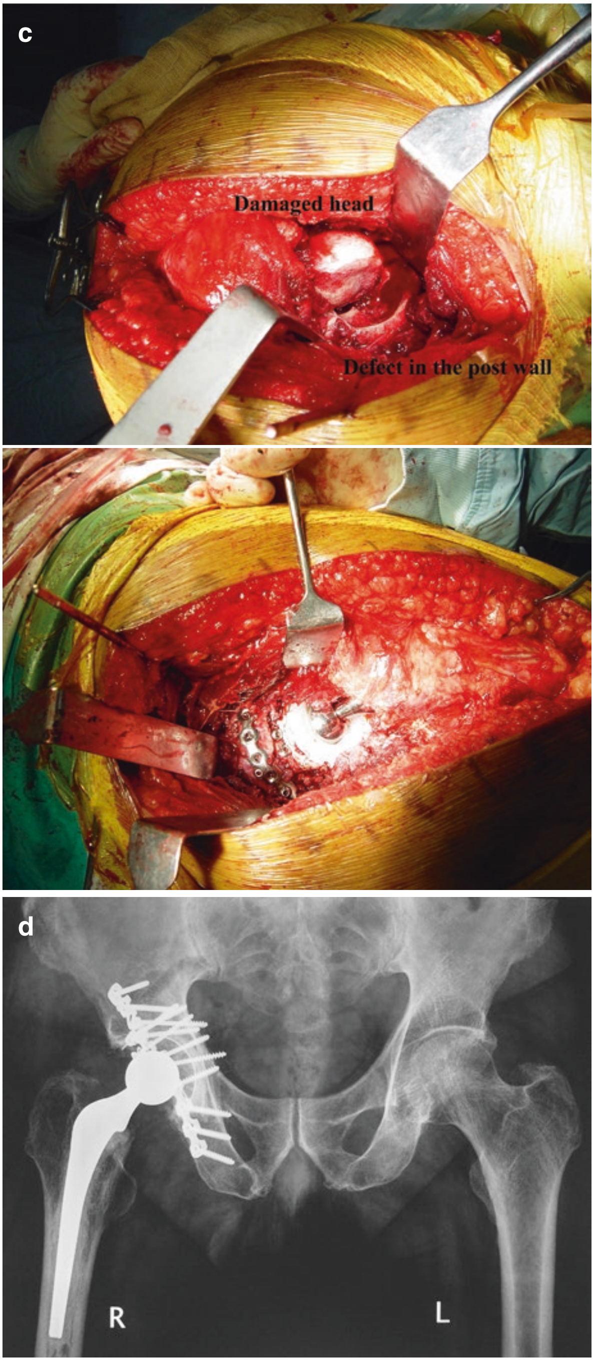


Fig. 8.6 (continued)

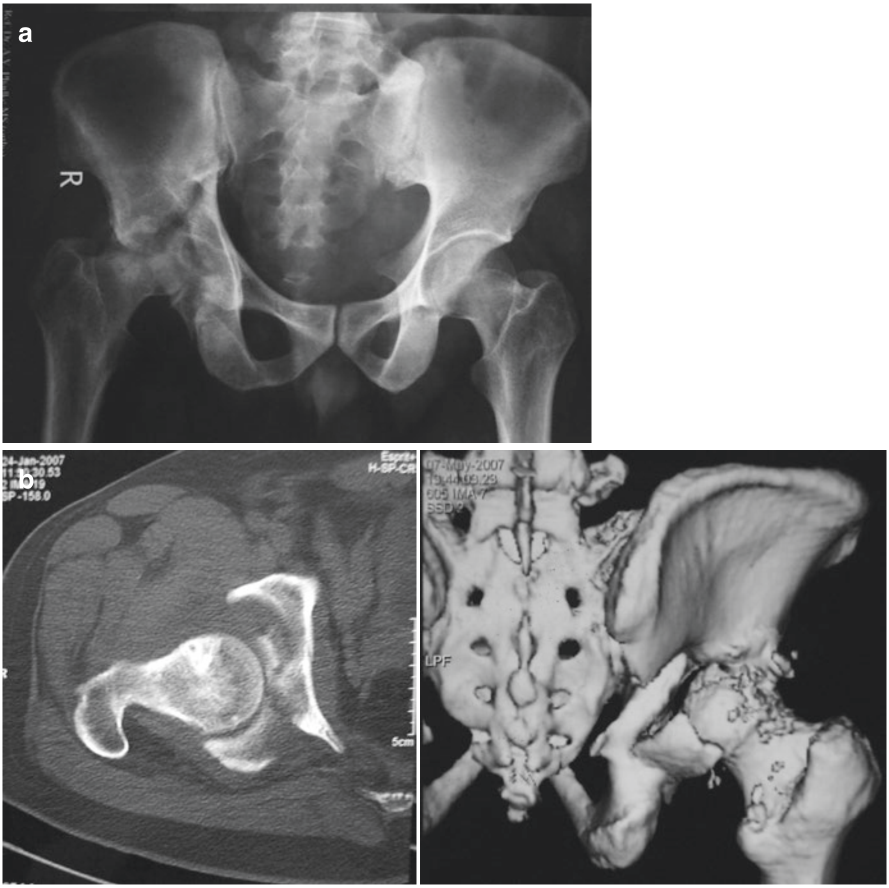


Fig. 8.7 (**a**) Pre-operative AP pelvis radiograph of a 32 year-old patient with a both-columns acetabular fracture. (**b**) 3D CT reconstructions of the fracture pattern. (**c**) Post-operative AP pelvis radiograph showing a cage-cup construct with fixation of the posterior column. A trochanteric osteotomy had to be performed to access the acetabulum during the procedure

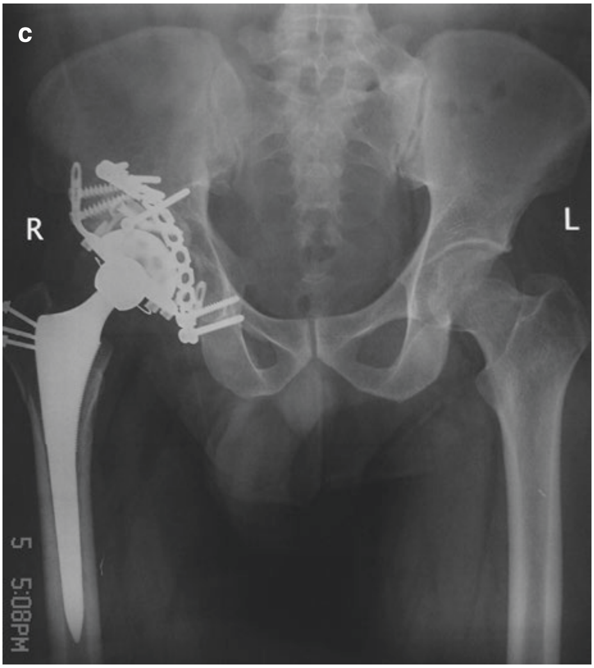


Fig. 8.7 (continued)

cases, 28 (93%) THAs had a minimum follow-up of 2 years. The authors reported that the fracture pattern was of the elementary type in 8 of 30 hips (27%, posterior wall fracture in 6 hips, transverse fracture in 2 hips) and associated type in 13 of 30 hips (43%, T-type fracture in 5 hips, transverse-posterior wall fracture in 4 hips, posterior column/posterior wall in 3 hips, and associated both column in 1 hip). The fracture pattern was unknown in 9 of 30 hips. Nine of 30 hips (30%) had radiographic evidence of osteonecrosis of the femoral head, and 6 of those had confirmed traumatic dislocations at the time of their initial injury. A majority of patients underwent the anterolateral approach, and only 9 of 30 hips were performed using the posterolateral approach. No acetabular components were revised for aseptic loosening. Five-year survival with revision for any reason as the endpoint was 88% (95% confidence interval, 0.70–0.96). Failures were related to infection. Three hips (11%) underwent resection for infection, with all being treated with two-stage arthroplasty. Harris hip scores improved from a median of 39 preoperatively (range, 3–87) to 82 at the most recent follow-up (range, 21–100; $p < 0.01$). Fifteen of 28 hips (54%) had a good or excellent result, 3 (11%) had a fair result, and 10 (35%) had a poor result. Two patients (7%) experienced at least one dislocation postoperatively. Both were treated with a closed reduction and hip abduction brace treatment.

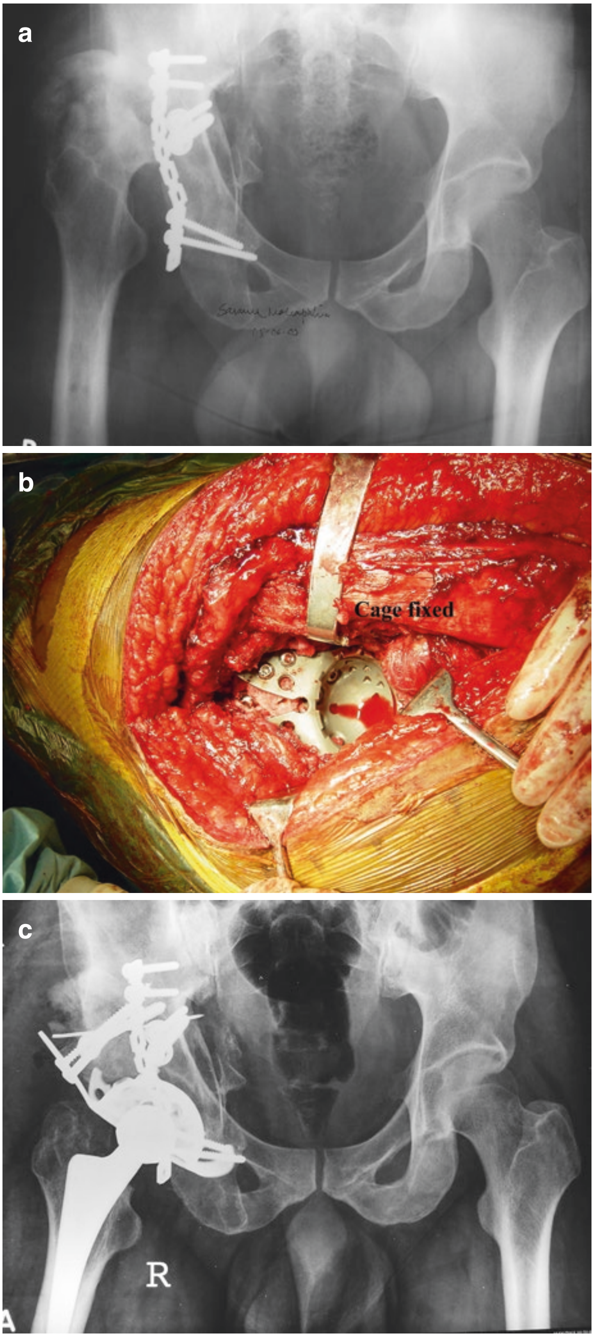


Fig. 8.8 (**a**) Pre-operative AP pelvis radiograph of a patient with failed acetabular fracture fixation. (**b**) Intra-operative images showing fixation of a cage and the femoral head autograft. (**c**) Post-operative images displaying the cage-cup construct and restoration of the hip center of rotation

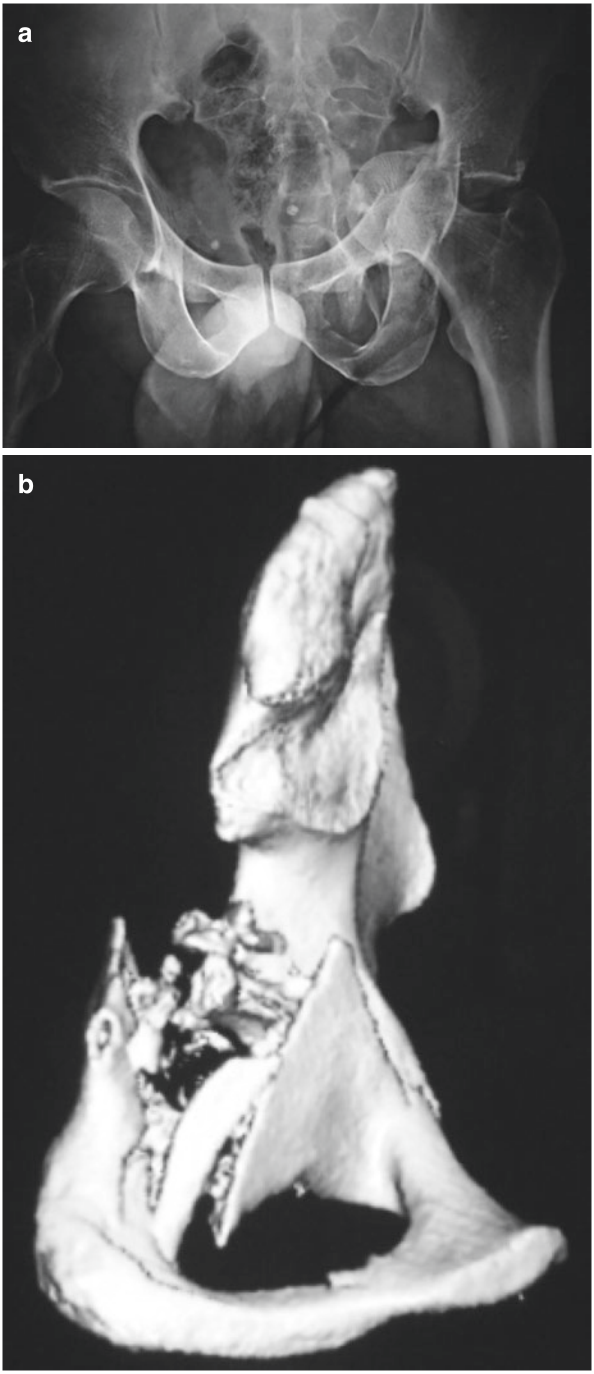


Fig. 8.9 (**a**) Pre-operative AP pelvis radiograph of a comminuted both columns fracture. (**b**) 3D CT reconstruction of the fracture pattern. (**c**) Post-operative radiographs showing posterior column fixation and cage cup construct

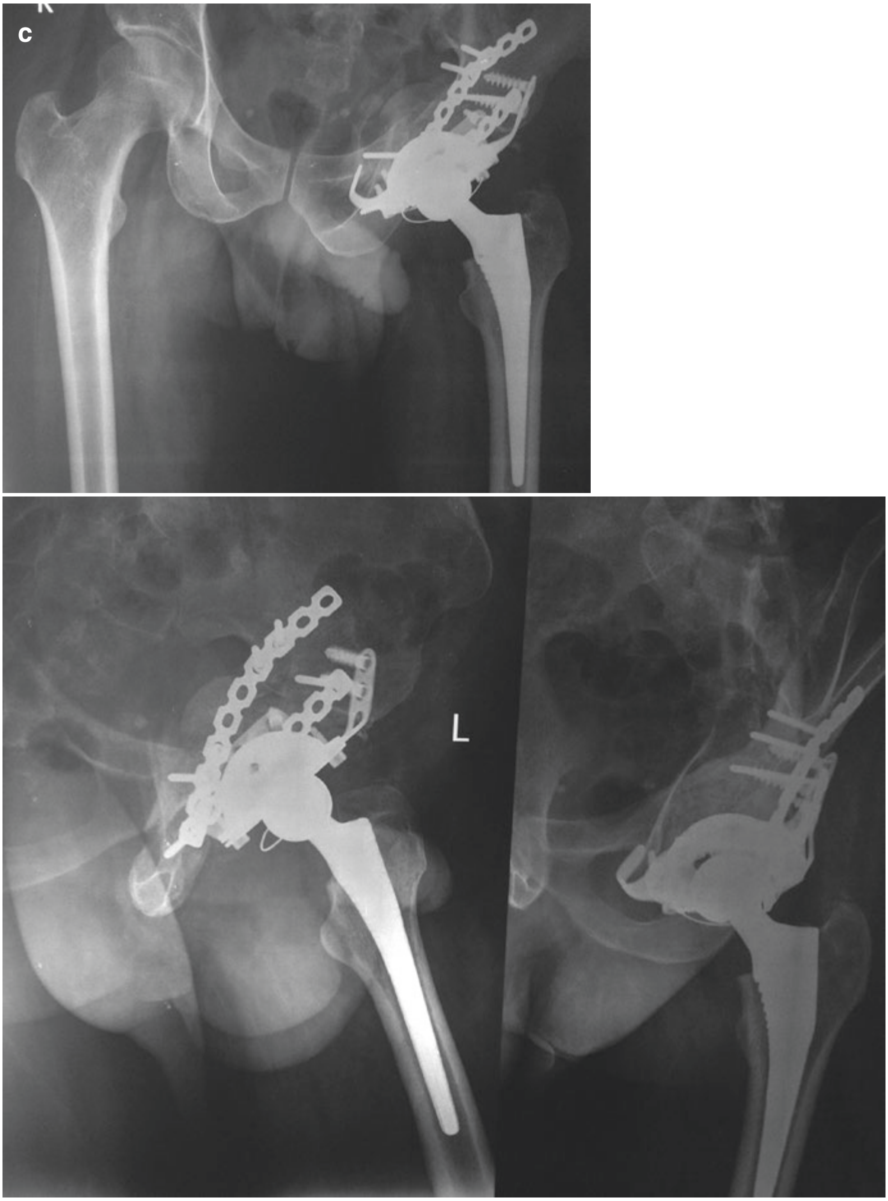


Fig. 8.9 (continued)

Another promising study from the Hospital for Special Surgery describes their results with 32 THAs performed for posttraumatic arthritis after acetabular fractures; 24 patients were treated with a prior ORIF, and 8 were managed conservatively [18]. Average time from fracture to THA was 36 months (range, 6–227 months). The average follow-up was 4.7 years (range, 2.0–9.7 years). With regard to fracture classification, 16 patients (50%) had simple fracture patterns, and 16 patients (50%) had associated patterns. One patient had a concomitant pelvic fracture. The most common fracture patterns were isolated posterior wall fractures in 13 (41%) cases, both-column fractures in 4 (13%) cases, and posterior column–posterior wall in 5 (16%) cases. Cementless acetabular components were used in all 32 cases. The authors reported 79% 5-year end point survival for revision, loosening, dislocation, or infection. Survival for aseptic acetabular loosening was 97%. Six (19%) revision surgeries were necessary due to infection (two cases), aseptic acetabular loosening (one case), aseptic femoral component loosening (two cases), and a liner exchange for dislocation (one case). Revision surgery correlated with nonanatomic restoration of the hip center and a history of infection ($P < 0.05$). Two other patients also had at least one dislocation, but they both responded to conservative treatment with closed reduction and bracing, which resulted in a dislocation rate of 9%. Harris hip scores increased from 28 (0–56) to 82 points (20–100).

Studies from China have reviewed outcomes at 5 years and 6.3 years after THA for acetabular fractures. Zhang et al. retrospectively analyzed 53 patients (55 hips) who underwent THA because of failed treatment for acetabular fractures. The mean duration of follow-up was 64 months (range, 32–123 months) in 49 patients [23]. Thirty-three hips (60%) had simple fracture patterns, and 22 (40%) had complex patterns. The most common patterns were posterior wall fractures in 28 (51%) hips, transverse-posterior wall fractures in 13 (23%) hips, and fractures of the posterior column and posterior wall in 6 (11%) hips. Patients treated without ORIF underwent a posterolateral approach to the hip. However, in patients with prior fixation, a posterolateral approach was used in 28 hips, while a direct lateral approach and a posterolateral plus anterolateral approach were used for removal of hardware in 2 hips, respectively. The authors used cement-less cups in 48 of 55 hips, and cemented cups in 7 hips with 5 of them in combination with acetabular reinforcement rings (ARRs). The authors report that with revision or definite radiographic loosening as the end-point, the 5-year survival in their study was 100%. Three cement-less acetabular components had a partial radiolucency (zones 2 and 3 [4]); in 2, the radiolucency was less than 1 mm wide, and in 1, it was more than 2 mm wide. All of them were associated with a good or excellent Harris hip score and were considered stable. A complete radiolucency, from zones 1 to 3, more than 2 mm wide, was seen in 1 cemented cup. None of the acetabular cups or ARRs showed any evidence of migration. All bone grafts completely incorporated without any complications. Complications included 1 dislocation and 3 sciatic nerve injuries. No instances of deep wound infection were present. The dislocation was successfully treated with closed reduction with no recurrence. The mean duration of follow-up was 64 months (range, 32–123 months) in 49 patients (51 hips); 4 patients were lost to follow up. The average Harris hip score increased from 49.5 (range, 22–78) before surgery to

90.1 (range, 56–100) at the latest follow-up examination ($P < 0.001$). Results were excellent for 36 hips, good for 11, fair for 2, and poor for another 2. In the ORIF group, the average Harris hip score increased from 9.5 (range, 30–78) to 90.1 (range, 56–100) ($P < 0.001$), and in the non-ORIF group, it increased from 54.3 (range, 22–76) to 92.4 (range, 56–100) ($P < 0.001$). Moreover, the average postoperative Harris score was significantly higher in the ORIF group than in the non-ORIF group ($P < 0.05$). Similar significant improvements in average Harris hip scores were also seen both in patients with cement-less acetabular reconstructions and in those with cemented cups ($P < 0.001$). Another study from China evaluated outcomes of cement-less acetabular components at 6.3 years (range, 3.1–8.4 years) after surgery in 31 hips with posttraumatic arthritis after acetabular fractures [10]. Of the 31patients, 19 (65%) had undergone ORIF (open-reduction group), and 12 (35%) had received conservative treatment for the acetabular fractures (conservative-treatment group). 14 patients (45%) had elementary fracture patterns while 17 patients (55%) had associated fracture types. The posterolateral approach to the hip was used in all patients. At the follow-up of 6.1 years, the authors reported no infection and no revision surgery. The rate of anatomical restoration of center of hip rotation was 100% (19/19) in the open-reduction group, and 67% (8/12) in the conservative-treatment group ($P = 0.02$), compared with 93% (13/14) in the simple group and 82% (14/17) in the complex group ($P = 0.61$). Anatomical restoration was positively related to fracture treatment ($r = 0.48$; $P = 0.006$), but it had no relation to fracture pattern ($r = 0.16$; $P = 0.40$). By the final follow-up evaluation, six acetabular components had partial radiolucent lines at the bone implant interface, all 1 mm or less; and they occurred in zone 1 in five hips and in zone 3 in one hip. Osteolysis was not observed in any patient. Of the patients with structural bone graft, only one had minor graft resorption. Four patients (13%) had complications after THA. One patient whose complex fracture was treated conservatively fell 4 years after surgery, causing posterior hip dislocation. Another patient whose complex fracture was treated with ORIF had posterior hip dislocation 14 days after surgery because of failure to adhere to posterior hip precautions. Both patients were successfully treated with closed reduction; neither patient had a recurrent dislocation until the latest follow-up evaluation. The sciatic nerve was injured during THA in one patient in the open-reduction group who had a complex fracture. The patient had dorsal pedal numbness and drop foot after surgery. The average Harris hip score increased from 49 ± 15 before surgery to 89 ± 5 after surgery, and 29 patients (94%) had either excellent or good results. The average Harris hip score for the open-reduction and conservative-treatment groups increased to 87 ± 6 and 91 ± 3 ($P = 0.07$), respectively, after surgery; for the complex and simple groups, it increased to 88 ± 6 and 90 ± 4 ($P = 0.25$), respectively. There was no significant difference between the open-reduction and conservative-treatment groups or between the complex and simple groups regarding the number of hips with excellent and good results.

The results of THA after acetabular fracture are humbling at 10 years when compared to THA for cases unrelated to posttraumatic arthritis. Morrison et al. performed a retrospective case-control study for patients at their institute between 1987 and 2011 [15]. During this period, the authors performed 95 THAs after acetabular fracture; of those, 74 (78%) met inclusion criteria and had documented follow-up beyond 2 years in their institutional registry. They also selected 74 matched patients based on an algorithm that matched patients based on preoperative diagnosis, date of operation, age, gender, and type of prosthesis. All surgeries were performed through the posterolateral approach. The primary outcomes were revision and incidence of complications. Secondary outcomes were radiographic signs of heterotopic ossification or implant loosening. The majority of acetabular fractures were treated by ORIF (58 of 74 [78%]), whereas 16 of 74 (22%) were treated nonoperatively. The most frequent type of fracture involved the posterior wall, accounting for 31% of all injuries. Fractures involving both columns were seen in 16%, whereas other fracture types were less common and were observed in less than 10% of patients. 49% of patients had elementary fracture types while 51% of patients had associated patterns. The 10-year survivorship after THA was lower in patients with a previous acetabular fracture than in the matched cohort (70%, 95% confidence interval [CI] 64–78% versus 90%, 95% CI 86–95%; $p < 0.001$). Younger patients (<60 years) had worse THA survivorship after acetabular fractures than did older patients (60%, 95% CI 51–69% versus 83%, 95% CI 72–94%; $p < 0.038$), and both had inferior survivorship to the matched cohort (92%, CI 87–97% and 96%CI 92–99%; $p < 0.001$). The 10-year survival for THA after a simple acetabular fracture was 83% (95% CI 77–89%) as compared with 60% (95% CI, 52–68%; $p = 0.032$) for associated fractures. Patients with previous acetabular fracture had a higher likelihood of developing infection (7% [five of 74] versus 0% [zero of 74]; odds ratio [OR], 11.79; $p = 0.028$), dislocation (11% [eight of 74] versus 3% [two of 74]; OR, 4.36; $p = 0.048$), or heterotopic ossification (43% [32 of 74] versus 16% [12 of 74]; OR, 3.93; $p < 0.001$). In patients with previous acetabular fracture, 13 patients (20%) were revised for loose acetabular component, 6 patients for wear and joint instability (8%), 2 for infection, and 1 each for femur fracture, loose femoral component, and recurrent dislocation. Revisions for the matched cohort included 11 patients for cup loosening and one patient for recurrent dislocations.

Of the 51 patients in the acetabular fracture group, who did not have a revision, 6 had no radiographs available, 46 had well-fixed components, and none had cup loosening. Of the 62 control patients without revision, 3 had no radiographs available, 59 had well-fixed components, and none had cup loosening.

To summarize the outcomes of THA in posttraumatic arthritis after acetabular fractures, Makridis et al. performed a systematic review in 2014 [11]. In total 654 patients were reviewed (659 hips) with a median follow-up of 5.4 years (range 12 months – 20 years). Median follow-up was 3.9 years (range 12 months–12 years) in the acute THA group and 6.3 years (range 12 months – 20 years) in the delayed THA group. A large majority of fractures were posterior wall fractures (140 patients; 21.4%) followed by transverse/posterior wall fractures (63 patients; 9.6%), posterior column-posterior wall fractures (51 patients; 7.8%), and both column fractures (49 patients; 7.5%). Treatment of acetabular fractures was only described in 625 fractures of which 473 fractures (75.7%) were treated with ORIF and 152 fractures (24.3%) nonoperatively. The majority of the studies reviewed by the authors reported no failure of initial treatment of acetabular fractures. 237 patients (36%)

were treated with acute total hip arthroplasty. Delayed total hip arthroplasty was performed in the remainder of the reviewed patients following either operative or nonoperative management of the initial acetabular fracture. In the early-THA cases, the median interval between time of injury and total hip arthroplasty was 10 days (1–29). In the delayed cases, the average time from injury to THA was 6.6 years (2 months–45 years).

With regard to acetabular components, an uncemented acetabular component was used in 484 patients (80.1%) and a cemented one in 120 patients (19.9%). For femoral components, the data was available in 569 hips with 340 patients (59.8%) receiving an uncemented and 229 patients (40.2%) a cemented femoral component. An antiprotrusion acetabular cage was rarely used, and acetabular bone graft was used in all cases. Anterolateral and posterolateral surgical approaches were used in a majority of the cases. In the early THA group, Kaplan–Meier survivorship analysis with any loosening, osteolysis, or revision as the end-point revealed that the 10-year cup survival was 81%. In the late THA group, this percentage was 76%. The log-rank test showed that this difference was not significant ($P = 0.287$). In the late THA group where the proportion of uncemented and cemented implants were available, Kaplan–Meier survivorship analysis with any loosening, osteolysis, or revision as the end-point revealed that the 10-year survival was 86.7% for the uncemented cups and 81% for the cemented. The log-rank test showed that this difference was not significant ($P = 0.163$). In the early THA group, 13 cups (7.5%) out of 173 implants were revised. Four cups were revised for aseptic loosening, one for traumatic loosening, six for dislocation, and two for infection. It was unclear how many of these cups were cemented and how many were uncemented. In the late THA group, 35 cups (9.6%) out of 365 implants were revised. Sixteen cups (45.7%) were uncemented (13 were revised for aseptic loosening, 1 for traumatic loosening, and 2 for infection). Nineteen cups (54.3%) were cemented (17 were revised for aseptic loosening, 1 for dislocation, and 1 for infection). The three most common complications were heterotopic ossification, infection, and dislocation which occurred in a total of 292 out of 654 patients (44.6%). The Harris hip score was used to describe the functional outcome with a median value of 88 points. Regardless of the type of treatment, and according to the Harris hip score, younger patients achieved better clinical outcomes than older patients (92.94 ± 4.48 versus 81.68 ± 4.58, respectively) ($P < 0.001$). Almost all of the studies did not compare Harris hip scores for acute versus delayed THA. Thirty-three patients died, and the overall mortality rate was 5%. No patient died in the acute perioperative phase. The minimum time of postoperative mortality was 4 months after surgery and maximum within 10 years after surgery.

In conclusion, THA for posttraumatic arthritis associated with acetabular fractures shows promising results and satisfactory functional and radiological outcomes. However, there are no prospective studies to compare directly the outcomes following acute or delayed total hip arthroplasty secondary to acetabular fractures. The largely retrospective data available in the literature indicate that the clinical outcomes, revision rates, and implant survivorship do not differ when either an early or a late THA is performed. The overall revision rates after THA following acetabular fractures are substantially higher than those following a conventional primary THA, and, hence, a multispecialty treatment approach of these challenging injuries is essential.

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Chapter 9
Post-traumatic Arthritis of the Proximal Femur

Raj M. Amin, Erik A. Hasenboehler, and Babar Shafiq

Key Points

- Optimal treatment for posttraumatic arthritis of the proximal femur is patient specific.
- Hip arthroscopy is on the forefront of treatment modalities.
- Arthroplasty for proximal femur fractures is increasingly indicated during the index fracture.
- Varus malunion is a common mode of failure following treatment of femoral neck fractures.

Introduction

Epidemiology

Symptomatic posttraumatic osteoarthritis (PTOA) occurs in approximately 12% proximal femur fracture patients [1–3]. In addition to causing substantial patient burden, PTOA is an expensive problem that accounts for $3.1 billion in annual treatment spending in the United States [3]. With an increasingly elderly population and advances in medical care which have improved overall longevity, the incidence of

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_9

PTOA figures will increase [4]. As such, an understanding of the disease and treatment options currently available is a key component of the treating musculoskeletal practitioners skill set.

Pathophysiology of Failure

Though traumatic osteoarthritis is thought of as a long-term consequence after proximal femur fracture, it begins immediately after injury. The amount of chondral damage occurring during this time period is difficult to quantify and is due to a number of factors including acute inflammation, pressure necrosis, and direct injury.

Given the significant amount of soft tissue disruption and local hemorrhage, the postfracture milieu contains a high proportion of chondrotoxic mediators. In the newly fractured proximal femur, this provides an opportunity for cytokines, matrix metalloproteinases, interleukins, neutrophils, and reactive oxygen species to cause articular disruption [5]. Additionally, in fracture patterns where the joint capsule is not violated, a pressure necrosis phenomenon from fracture hematoma may accelerate chondrocyte apoptosis. This has been likened to a "compartment syndrome of the hip." As such, there may be a theoretical benefit to early direct capsular decompression in proximal femur fractures to mitigate not only avascular osteonecrosis but also articular pressure necrosis. However, the general evidence-based consensus is equivocal regarding the utility of this surgical option in the prevention of osteonecrosis [6].

Perhaps the most acute causative factor in PTOA is the direct chondral damage resulting at the time of injury (Fig. 9.1). This is particularly true in high-energy proximal femur fractures, which are usually seen in younger patients [6]. These cells are subject to matrix damage, disruption of the collagen fibrils, and potentially full thickness articular damage depending on the loading rate and force [7]. Factors predicting worse instantaneous cartilage injury include fracture mechanisms that have simultaneous compression and shear forces such as Pipkin IV fracture dislocations (Table 9.1), and prolonged increases in both load borne by the articular surface and duration of the increased load [7].

With repetitive loading, joint instability and incongruity exacerbate the acute chondral compromise in the form of increasingly symptomatic PTOA. Within the proximal femur, the factors particularly involved include vascular insufficiency, which commonly precedes joint incongruity, while abnormal joint reactive forces via planar malalignment increase instability and contact pressures. The resultant lack of bony subchondral support diminishes the stress-sharing capacity of underlying trabeculae. As such, increased stresses are seen by the overlying articular surface making it prone to thinning and early arthrosis [7].

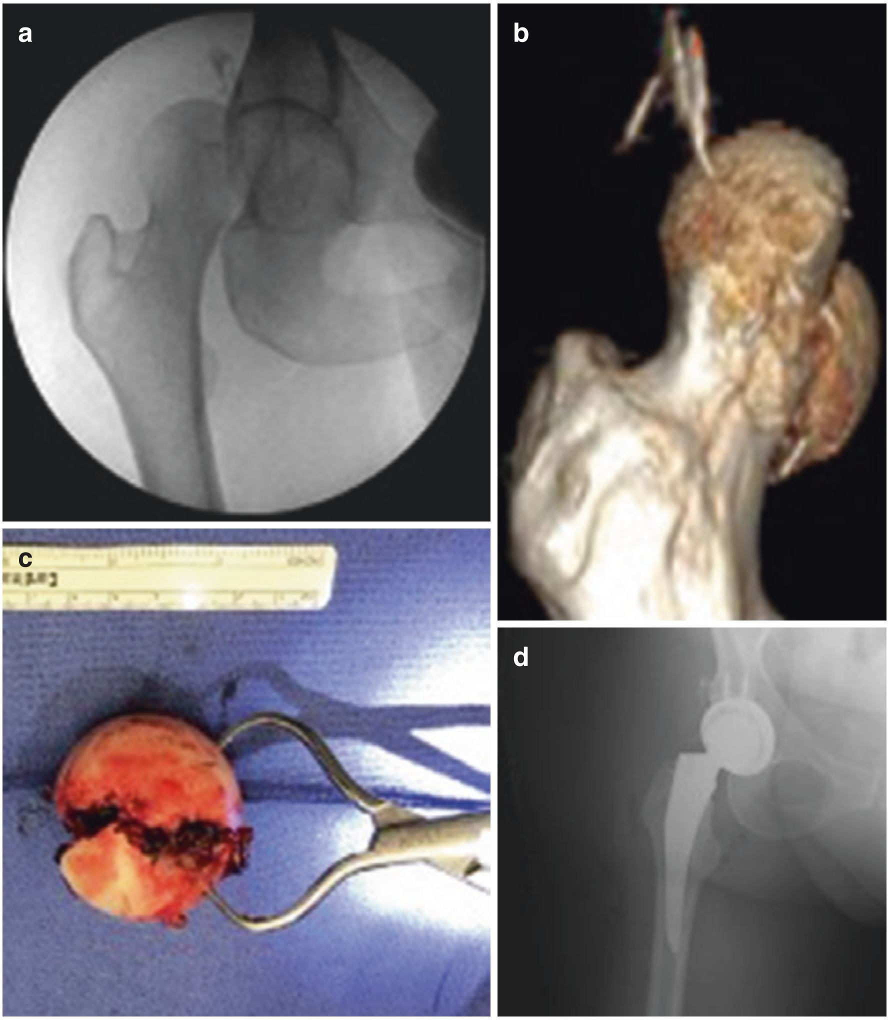

Fig. 9.1 (**a**) Radiograph demonstrating Pipkin IV fracture dislocation in a 48-year-old patient. (**b**) 3-D reconstruction CT image depicting substantial femoral head collapse. (**c**) Intraoperative image of excised femoral head with split-depression fracture. (**d**) Treatment with index total hip arthroplasty (THA)

Table 9.1 Pipkin classification

Type	Fracture pattern
I	Infrafoveal
II	Suprafoveal extension
III	Type I or II with associated femoral neck fracture
IV	Type I or II with associated acetabular fracture

Fracture Specifics

Hip Dislocation

Though the articular surface in isolated femoral head fractures experiences substantial shear forces, prompt reduction generally results in minimal long-term consequences. In isolated dislocations without hip fracture, prompt reduction results in excellent long-term clinical outcomes [8]. At 11-year follow-up, six of seven patients with isolated dislocations had good to excellent Thompson and Epstein objective outcome scores and only one patient had mild pain with cystic changes on radiograph. Therefore, the poor functional outcome in 53% of posterior dislocations and 25% of anterior dislocations seen in this study were attributed to other injuries associated with the dislocation as rates of good to excellent subjective clinical outcomes are 85–100% in isolated hip dislocations [8].

Femoral Head Fracture

PTOA following femoral head fracture results primarily from direct chondral injury. In the long term, failure following femoral head fractures results from avascular necrosis, which is apparent in 10% of patients at 12 months postinjury [9]. Additionally at a mean of 12 months postoperatively, Scolaro et al. demonstrated 12% early fixation failure rate in a population primarily treated with open reduction internal fixation (53%), fragment excision (25%), and hemiarthroplasty (2%) [9]. At a mean of 5 years postinjury, PTOA is present in nearly 20% of patients [1]. Factors predicting worse outcome include nonsurgical management and increasing Pipkin type (Table 9.1) [1, 9, 10].

Fractures of the femoral head present a relatively difficult treatment challenge as both exposure and fixation options are limited. Pipkin I fractures may be treated nonoperatively with open fragment excision or internal fixation [11]. Recently, internal fixation has been described using an arthroscopic approach though long-term outcomes are pending [12]. In large Pipkin I fracture fragments, open reduction with internal fixation (ORIF) has demonstrated better clinical and radiographic outcomes as compared to fragment excision [13, 14].

In Pipkin III fractures, Scolaro et al. recommend strong consideration of arthroplasty based on 100% failure of ORIF in their study [9]. However, AVN-related failures have been markedly reduced with the vascular preserving surgical hip dislocation popularized by Gans [15]. This is particularly true in Pipkin I and II fractures treated with early (<6 hour) surgical hip dislocation – one study with a mean of 36-month follow-up found 0% rate of osteonecrosis, and 100% union rate [11]. Another study demonstrated 85% excellent clinical outcomes (HHS score >80) utilizing a surgical hip dislocation in all operatively managed Pipkin fractures and 8% avascular necrosis rate [16].

While traditionally reserved for Pipkin I and II fractures, a limited series of patients with Pipkin IV fractures demonstrated 88% success (no PTOA) with a modified Gibson approach. This posterior approach allows for increased anterior acetabular exposure through a modification of the proximal exposure via development of the plane between the gluteus maximus and tensor fascia lata rather than the gluteal splitting seen in the Kocher-Langenbeck approach. However, longer-term and larger-scale studies are needed to substantiate this approach for all Pipkin IV fractures [17]. We routinely use a modified Smith-Peterson approach for fixation for infrafoveal fractures while reserving the surgical hip dislocation of Ganz for suprafoveal and Pipkin type IV fractures.

Femoral Neck

PTOA in femoral neck fractures is primarily a failure of fixation and vascularity. The latter complication is particularly elevated in femoral neck fractures given the intracapsular location and tenuous blood supply to the femoral head. This may be compromised during the initial fracture or iatrogenically during fixation. As such, proximal femur fractures with higher displacement are at greatest risk of vascular injury and resultant long-term avascular necrosis (Fig. 9.2). At 5 years postinjury, 20% of femoral neck fractures repaired with internal fixation will undergo revision arthroplasty primarily due to avascular necrosis [18].

In elderly patients, fixation failure in the form of nonunion occurs in approximately 4–5% of stable femoral neck fractures (Garden 1 and 2, Table 9.3) patients [19, 20]. However, all-cause fixation failure is nearly 12–34.6% in this population due to avascular necrosis, nonunion, and fixation failure [21–24]. In younger patients with femoral neck fractures (<60 years old), Slobogean reported a substantially elevated rate of both malunion and nonunion at 7.1 and 9.3%, respectively [25]. Factors predicting a high likelihood of osteosynthesis failure include subcapital fracture location, Pauwel type 3 fractures (Table 9.2), Garden III or IV fractures (Table 9.3), and apex anterior tilt of the femoral head when treated with cancellous screws [26–28].

Pauwel III fractures provide a particularly difficult treatment challenge. Initial treatment with cannulated screws demonstrated significantly higher nonunion rates [29]. Moreover, treatment of this fracture pattern with cancellous screw fixation has also demonstrated significantly lower cycles to 15 mm shortening compared to dynamic hip screw or blade plate fixation [30]. This is substantial as recent data demonstrate femoral neck shortening of ≥10 mm has been implicated in worse functional outcomes including statistically lower Harris Hip Scores and SF-36 physical component scores [31]. Given the higher shear forces experienced in Pauwel III fractures, the use of autologous bone grafting at the time of the index procedure has been tried with good short-term success. In a study of 17 patients with Pauwel III fractures, 100% healed at a mean of 14.1 weeks, and less than 6% required arthroplasty at 27-month follow-up [32].

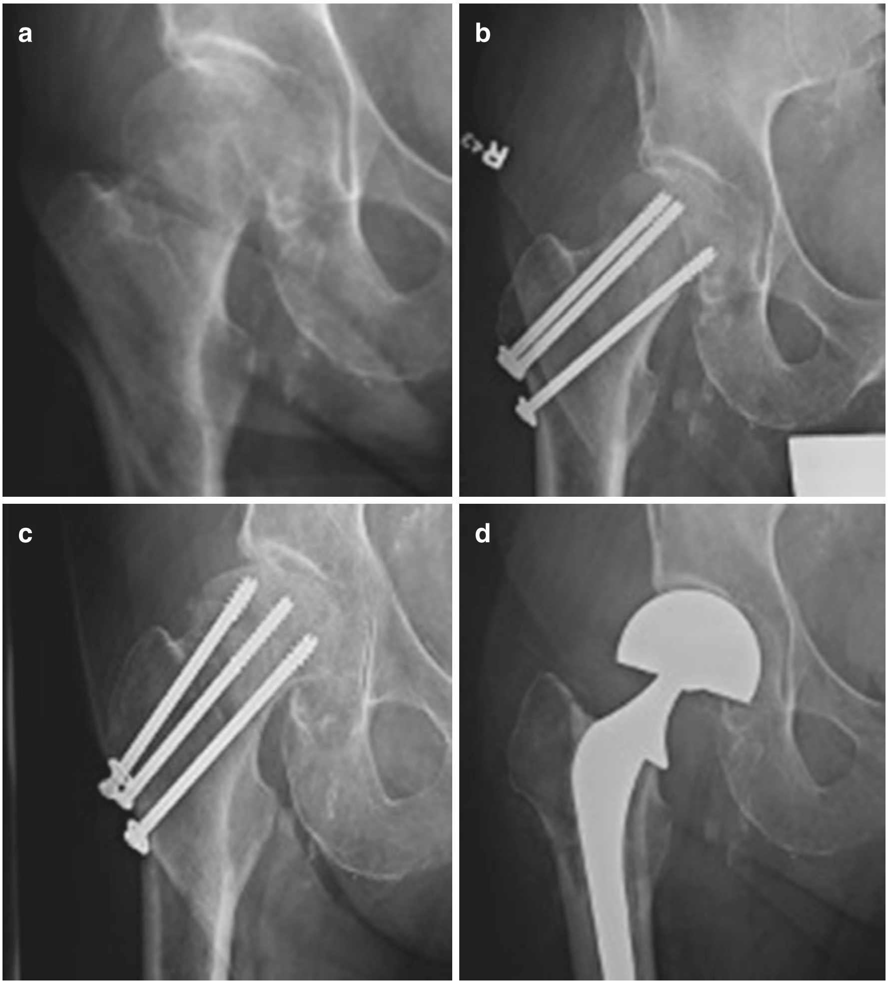

Fig. 9.2 (**a**) Nondisplaced femoral neck fracture. (**b**) Immediate postoperative imaging. (**c**) Femoral head collapse 6 months following index procedure. (**d**) Conversion to hemiarthroplasty

Table 9.2 Pauwel classification

Type	Fracture angle (degrees)
I	<30
II	30–50
III	>50

Table 9.3 Garden classification

Type	Fracture pattern
I	Incomplete
II	Complete, nondisplaced
III	Complete, partially displaced
IV	Complete, highly displaced

Intertrochanteric

PTOA following intertrochanteric fractures primarily occurs due to fixation failure (Fig. 9.3). Fortunately, due to substantial vascular supply, soft tissue preservation with closed reduction techniques, and robust cancellous bone, fixation failure occurs in only 1–2% of trochanteric fractures treated with intramedullary nailing [33, 34]. Factors predicting increased nonunion rate are the essential components of "unstable" trochanteric fractures including reverse obliquity, subtrochanteric extension, lateral wall comminution, and loss of medial calcar support [35–37]. However, the most important factor predicting PTOA via uneven joint force distribution is malreduction [33, 38]. Alteration of greater than 5 degrees of varus in the coronal plane,

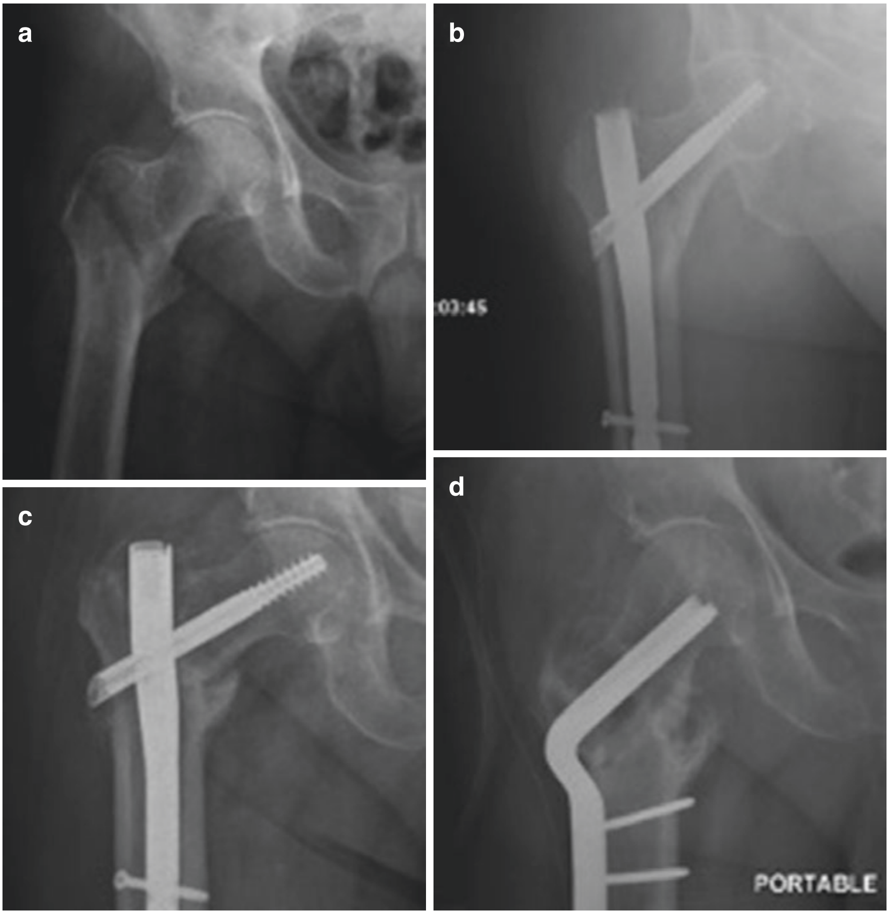

Fig. 9.3 (**a**) Minimally displaced intertrochanteric fracture. (**b**) Immediate postoperative radiographs. (**c**) Varus failure 6 months after index procedure. (**d**) Valgus intertrochanteric osteotomy with revision open reduction internal fixation

10 degrees in the sagittal plane, and 15 degrees in the axial plane focuses load on the superior femoral head, leading to arthrosis [33, 38].

Additionally, cut-out is of particular concern in trochanteric fractures (Fig. 9.4). It is estimated to occur in approximately 2% of patients treated with intramedullary nailing [39, 40]. Factors predicting cut-out including nonanatomic reduction, sub-optimal bone quality, and tip-apex distance greater than 25 mm [39–41].

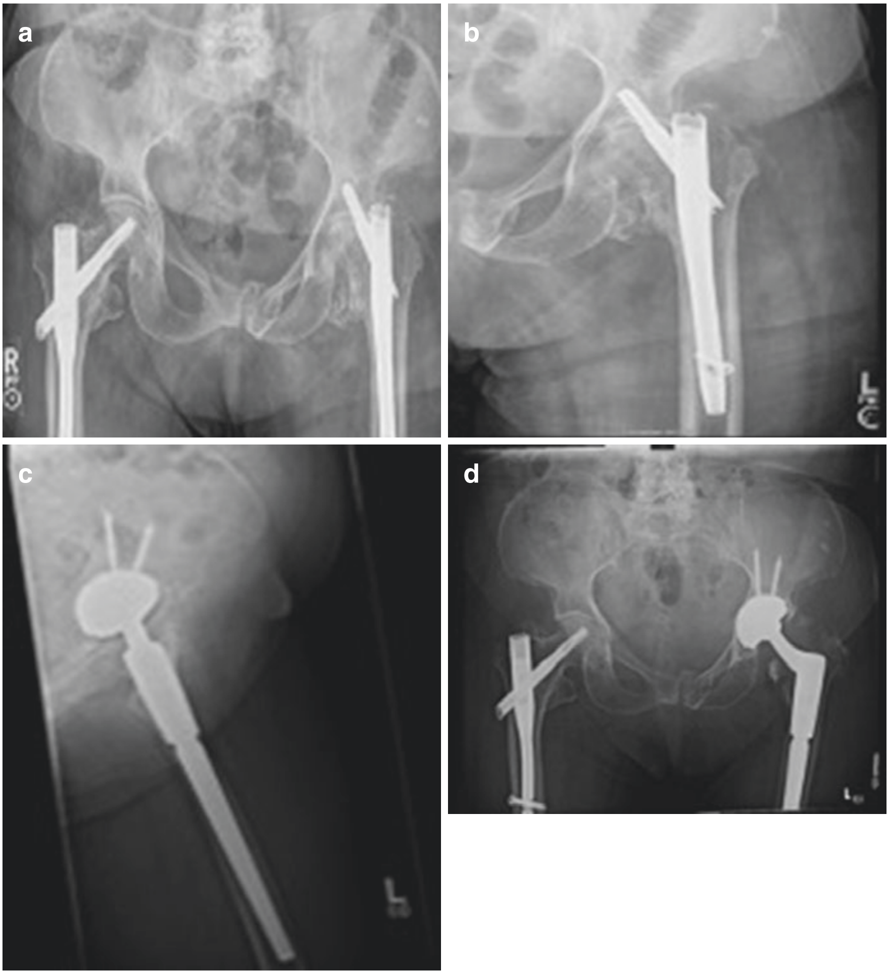

Fig. 9.4 (**a**, **b**) AP and lateral radiographs of left hip demonstrating cut out of cephalomedullary device. (**c**, **d**) One year following removal of hardware and conversion to THA

Management

The most definitive management for PTOA of the femoral head is hemi-, or total (THA), hip arthroplasty. These surgeries are supported by strong data demonstrating excellent outcomes, which have led some to opine that prevention of PTOA in patients with prefracture arthrosis should be accomplished with arthroplasty in amenable proximal femur fractures (7). However, arthroplasty in the setting of fracture is still associated with inherent risk over internal fixation including higher rates of wound infection, transfusion, and in-hospital morbidity. Additionally, due to limitations in prosthetic longevity, physiologically younger patients may be better served with osteosynthesis of native bone which may delay arthroplasty on average by 74 months [42]. Also, consideration of nonoperative and less invasive operative options are necessary in femoral head PTOA.

Nonoperative

There is a limited role for nonoperative management at the index injury time. This is usually reserved for critically ill patients. However, some Pipkin I fractures are amenable to initial nonoperative management but this option is usually not recommended as the rate of PTOA in nonoperatively managed Pipkin 1 fractures is 10% higher compared to operatively treated patients [10].

In the long-term, given that posttraumatic arthritis is a subset of osteoarthritis, it responds to the same conservative treatment that is well defined for the more common degenerative osteoarthritis. Antiinflammatory medications of varying potency and physical therapy are first-line, and often permanent, solutions to arthritic pain. Targeted intracapsular corticosteroid injections may also be of benefit from both a diagnostic and therapeutic perspective.

Operative

Arthroscopy

Hip arthroscopy for joint preservation is an increasingly common procedure. However, as with other joint arthroscopies, there is limited evidence to suggest that arthroscopic surgery of hip arthrosis provides improved clinical outcomes [43]. Chondral pathology at the time of hip arthroscopy for all indications is associated with 58-times greater risk for conversion to arthroplasty compared to patients without evidence of chondral damage [44]. Moreover several studies found that 16–44% of patients with arthrosis at the time of hip arthroscopy progress to THA within a maximum of 7 years [44–47].

Table 9.4 Tönnis classification

Grade	Radiographic changes
0	No evidence of OA
I	Sclerosis with minimal joint space narrowing or osteophytes
II	Moderate joint space narrowing with subchondral cyst formation
III	Severe joint space narrowing, subchondral cysts, deformation of femoral head

In the trauma population hip arthroscopy has more sparse literature. A study of 36 patients undergoing arthroscopy following closed reduction of hip dislocation found a 92% rate of loose bodies, and 78% rate of loose bodies in patients with imaging identifying concentric reduction and no loose bodies [48]. However, no outcome measures were reported in this study [48]. In a recent 2015 study of 13 patients undergoing hip arthroscopy following femoral head dislocation or acetabular fracture, 3.5-year follow-up demonstrated significant improvement in VAS scores and Modified Harris Hip Scores [49]. However, only Tönnis grade 0 or 1 (Table 9.4) patients were included in the study, and only 7 of 13 patients were femoral head dislocation patients. It is unknown how many of these patients had a concomitant acetabular fracture, which limits application to the proximal femur PTOA population. In another early study of hip arthroscopy in 38 patients, the diagnosis of arthritis resulted in an average Harris Hip Score increase of 18 and 14 points in patients with chondral injury, and arthritis, respectively, over a 10-month period [50]. However, the Harris Hip Score in those patients with a diagnosis of avascular necrosis decreased by 11 over the same time [50]. As previously mentioned, the etiology of PTOA in proximal femur fractures is strongly related to avascular necrosis. As such current data is inconclusive and further study is necessary to determine whether arthroscopy has a role in the treatment of young patients with severe PTOA following proximal femur fractures.

Hip Preservation

Management of femoral head chondral defects includes open and arthroscopic approaches. A number of treatments including chondroplasty, microfracture, fibrin adhesives, autologous chondrocyte transplantation, and osteochondral autologous transplants have been described [51, 52]. Microfracture has demonstrated positive clinical outcomes at 2-years postsurgery in Tönnis grade 0 or 1 patients [53]. However, there is a high rate of conversion to arthroplasty in patients with greater than Tönnis 1 radiographic changes. Additionally, other data suggests that microfracture does not improve patient reported outcomes at 2 years [54]. Other techniques including periacetabular osteotomy may have a role in the treatment of PTOA though this is yet to be described in the literature.

Osteotomy

Varus malunion is a common mode of failure following treatment of femoral neck fractures. If left uncorrected, PTOA occurs usually within 1 year of onset. In younger patients, and those where arthroplasty is relatively contraindicated, a valgus-producing osteotomy is a popular method of deformity correction to allow more even joint force distribution. This osteotomy may be inter- or subtrochanteric with success rates ranging between 85% and 100% [55]. One study of 60 patients with nonunited Garden III/IV, and Pauwel II/III, femoral neck fractures demonstrated 93% radiographic union rates and 90% good or excellent clinical outcomes after valgus subtrochanteric osteotomy and dynamic hip screw fixation [56]. However, postosteotomy AVN ranges from 10% and 40% although less than 10% of these patients are eventually converted to THA [55].

Core Decompression

In early-stage osteonecrosis, core decompression is a validated method of improving patient function and symptoms [57, 58]. In Fairbank's original study, 88% of Ficat stage I patients (mild osteopenia on radiograph and focal edema on MRI) required no further surgery at 11-year follow-up [58]. However, core decompression does carry the risk of postsurgical fracture and as such should be used with caution in those who are high fall risk. While the literature regarding core decompression is robust, there remains limited external applicability to the trauma patient at the present time. Most studies are based on level IV evidence and primarily evaluate for nontraumatic etiologies of femoral head osteonecrosis [58, 59].

Arthroplasty

Arthroplasty for proximal femur fractures is increasingly indicated during the index fracture. Elderly patients with displaced femoral neck fractures treated with arthroplasty have significantly lower complications, reoperation rates, less postoperative pain, and better overall function when compared to internal fixation [60]. Options for arthroplasty include THA and hemiarthroplasty. Hemiarthroplasty is commonly performed in those patients with relatively poorer health status, and risk factors for recurrent dislocation as the risk of dislocation for THA following fractures is four times higher than for THA performed due to arthritic indications [61–63] However prosthetic-induced acetabular wear causes substantial pain, and at 14 months postoperatively the clinical outcomes for THA are significantly better than hemiarthroplasty in properly selected patients [61, 62, 64]. Additionally, hemiarthroplasty confers no mortality or infection benefit at 4 years postoperatively when compared to THA, and uncemented prosthesis carries 720% higher chance of 5 year periprosthetic fracture when compared to cemented implants [61, 63, 65]. Therefore, the decision to perform hemiarthroplasty as the index procedure should primarily factor in poor projected patient longevity and household ambulation status as large database outcomes trend toward no difference in short-term complications or mortality in hemi- versus total hip arthroplasty [61, 63]. In younger patients aged 40–65, recent data indicate these patients may have greater clinical benefit and overall more cost-effective care with index THA (Fig. 9.1) [66].

With respect to painful PTOA, arthroplasty is the most definitive treatment option. Nearly 50% of patients with femoral head injury or acetabular impaction will require future arthroplasty [67]. The results of THA in patients with PTOA of the hip following acetabular or proximal femur fractures are inferior compared to primary degenerative OA. In one study of 1199 patients, 63 had THA for PTOA. They fared worse with respect to perioperative complications and demonstrated 13% revision rate due to persistent dislocation or infection at an average of 3.5 years postoperatively [42]. When compared to primary THA, patients undergoing THA conversion due to failed fixation of femoral neck fractures also have greater complications including deep infection, dislocation, and periprosthetic fracture [68]. However, 1 year functional outcomes were not substantially different [68].

As mentioned above, failure of fixation in intertrochanteric fractures increases superior femoral head arthrosis via coxa vara. Arthroplasty is a salvage option for the treatment of PTOA in this population as well. Compared to intertrochanteric fractures undergoing primary arthroplasty due to fracture complexity or poor bone quality, conversion arthroplasty resulted in significantly higher blood loss, operative time, and risk of postoperative periprosthetic fracture. However, 1 year mortality rates were not significantly different [69].

Hip Arthrodesis

Due to the above failure rate, and prospect of multiple revisions in young patients, alternatives to arthroplasty including arthrodesis have been employed. Patients considered for this procedure include those with monoarticular disease, high functional demand, and absence of lumbar or ipsilateral knee pathology [70]. Arthrodesis allows for preservation of bone stock and gluteal musculature and affords the patient satisfactory clinical outcomes while awaiting arthroplasty at a more age-appropriate time [70]. While no studies are available specifically addressing postfracture arthrodesis conversion to arthroplasty, one recent study evaluated 18 patients undergoing the aforementioned procedure. Eight of the 18 patients initially had arthrodesis for fracture. Patients undergoing conversion of previous arthrodesis to THA have substantial clinical improvement but also have increased incidence of neurologic injury and heterotopic ossification and tend to require use of ambulatory aids over long distances [71].

Conclusion

PTOA is a common sequelae following proximal femur injury. Initial forces result in chondral injury that is exacerbated by chronic changes in underlying bony support, which increases chondral contact pressures. Fortunately, advances in vascular-preserving approaches and an emphasis on prompt treatment of proximal femur fractures have improved long-term outcomes following these injuries. Given the number of treatment options with strong outcomes in the literature, the optimal treatment of symptomatic proximal femur PTOA is patient specific and ranges from osteotomy to arthroplasty to arthrodesis. With data demonstrating increasingly robust outcomes in PTOA hip arthroscopy, this surgical technique remains on the forefront of new treatment options and will continue to have an expanding role in the diagnosis and treatment of proximal femur PTOA.

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Chapter 10
Post-traumatic Arthritis of the Distal Femur

Karthikeyan Ponnusamy and Ajit Deshmukh

Key Points
- Distal femoral fracture nonunions are associated with a high burden of posttraumatic arthritis.
- Surgical options include osteoarticular autograft and allograft, realignment osteotomies, and unicompartmental or total knee arthroplasty.
- It is critical to restore the joint line in the treatment of posttraumatic arthritis of the knee.
- Higher levels of constraint may be necessary in TKA for posttraumatic arthritis.

Epidemiology

Adults sustain distal femur fractures at a rate of 4.5/100,000. Most of these fractures occur in female patients (67% vs. 33% in males) [1]. The two predominant age groups presenting with this injury are young adults who are involved in high-energy mechanisms and elderly who are involved in low-energy falls.

As with any periarticular fracture there are concerns that a combination of initial trauma to the articular cartilage and residual articular step-off or malalignment can accelerate the development of arthritic changes in the joint. One systematic review examined the impact of articular step-off for various joints. When they looked at studies for the distal femur, they only identified rabbit models that demonstrated

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_10

that as long as the step-off was smaller than the thickness of the articular cartilage, there was sufficient remodeling. However, in cases of step-off greater than the thickness of the articular cartilage and knee instability there could be rapid articular degeneration [2]. Another consideration is that residual malalignment from femoral malunion can alter joint loading and lead to degenerative changes. Kettelkamp et al. examined the significance of knee malalignment following fracture malunion and reported that degenerative knee changes developed at a range of 10–60 years after the fracture with an average of 31.7 years [3].

There are only a limited number of trials with sufficient follow-up to ascertain the clinical impact of posttraumatic arthritis from distal femoral fractures. One study by Rademakers et al. reported outcomes at a mean of 14 years (range 5–25 years) and found radiological evidence of moderate to severe osteoarthritis in 36% of patients, but 72% of these patients had good to excellent functional outcome scores [4]. Comparable results were reported by Thomson et al. at an average of 80 months follow-up, where 54% of patients had significant degenerative changes in the knee and 32% had no radiographic arthritic changes. None of these patients had undergone a total knee arthroplasty by the last follow-up [5]. To summarize, patients who have sustained a distal femoral fracture are at risk of developing radiological findings of arthritic changes, but clinical follow-up to 14 years afterward suggests almost three quarters of patients are not impaired by these findings. However, there remain a quarter of patients with radiological findings of posttraumatic arthritis that have more severe symptoms. Further follow-up is needed to determine if and when the previously asymptomatic patients with arthritic changes will become symptomatic.

Natural History of Distal Femur Fracture Healing

Most cases of distal femur fractures are treated surgically with the following implants as possible options: blade plates, locking plates, condylar screws, and retrograde intramedullary nails [6]. Current first-line management usually focuses on locking plates and retrograde intramedullary nails. In patients with significant medical comorbidities and limited ambulatory status, nonoperative options of functional bracing or casting can be considered.

Surgical treatment of distal femur fractures is usually successful, but the nonunion rate is reported to be 10%. Nonunions have been most commonly associated with open fractures, comminution, bone loss, and infection. Monroy et al. compared the results of revision ORIF for distal femur nonunions vs. ORIF for acute distal femur fractures and found that there was statistically no difference in time to union (mean of 7 months for nonunions vs. 5 months for acute fractures) and no statistical difference in range of motion and clinical outcome scores [7]. Ebraheim et al. in their systematic review on the subject of nonunions in distal femur fractures also found that open fractures and bone loss were the most common factors, followed by hardware failure and infection. After revision fixation of nonunions, 97% healed at an average of 9.86 months. They found that metaphyseal comminution was the fracture pattern most associated with nonunion. When the initial fixation utilized dynamic condylar screws and blade plates, there was a higher likelihood of nonunion than with locking plates. The most common fixation used for revisions was fixed angle platting with cancellous bone autograft, and this approach was successful in achieving union for 97.4% of patients at an average time of 7.8 months [6].

Patient Evaluation

Despite the generally successful results of the management of distal femur fractures, there will continue to be a subset of patients who will continue to have knee pain due to nonunion, posttraumatic arthritis, knee instability, or other etiologies. As with any patient, evaluation needs to begin with the history. Key aspects of the history that need to be determined is history regarding the treatment and outcomes from initial distal femur fracture management and time course of symptoms since then. Any aspects suggestive of infection must be highlighted, such as requiring antibiotics in the postoperative period, prolonged wound drainage, and repeat surgeries. Prior operative reports should be obtained if possible to identify the implant and facilitate the removal of the implant if warranted. The physical exam should focus on locating the prior surgical incisions, knee range of motion and ligamentous stability, and patellar tracking. Imaging should begin with standing AP radiograph, PA flexed, lateral, and sunrise views. Advanced cross-sectional imaging can be considered in cases of nonunion with CTs or localized articular injuries or ligamentous damage with MRIs. Prior hardware may affect the quality of the cross-sectional imaging, and specific metal suppression techniques should be considered.

Nonoperative Management of Posttraumatic Arthritis

Nonoperative management for posttraumatic arthritis includes the same treatment modalities as with osteoarthritis. McAlindon et al. conducted a systematic review of 29 treatment modalities to determine whether they should be utilized in nonoperative treatment of knee osteoarthritis. They reported that there was evidence supporting the use of intraarticular steroid injections, physical therapy and exercise, weight loss, acetaminophen, assistive walking devices, and oral or topical NSAIDs [8].

Operative Management of Posttraumatic Arthritis

Surgical options include osteoarticular autograft and allograft, realignment osteotomies, and unicompartmental or total knee arthroplasty (TKA) [9]. In cases of young and active patients with localized articular cartilage defects, osteochondral autograft or allografts can be considered. Gross et al. have published on the use of osteochondral allografts for both the distal femur and proximal tibia [10]. Their distal femur allograft survival rate was 95% at 5 years and 85% at 10 years. With an average of 10-year follow-up, they had 9 of 60 undergo subsequent total knee arthroplasty [10]. As reported by Kettelkamp et al., [3] malalignment after femoral fractures can lead to degenerative arthritic changes in the knee at an average of 30 years after initial injury. Consequently, realignment osteotomies can be a useful tool when managing a young patient with knee pain subsequent to malunited distal femoral fracture. Lustig et al. reported their experience of treating posttraumatic knee arthritis with osteotomy alone (femur, tibia, or both). They found that with an average of 3.8 years of follow-up, two of six patients with an intraarticular malunion went on to a total knee arthroplasty. Whereas, the 22 patients who had an extraarticular malunion did not have an arthroplasty during the time of follow-up. In addition, they found that, in general, patients had improvements in pain scores, but those with extraarticular malunion had the greatest improvement [2, 3].

For end stage posttraumatic arthritis, the treatment of choice would be TKA. However, for patients who undergo TKA for posttraumatic arthritis, it has been reported that they have higher complication rates than primary TKA for osteoarthritis. They have a higher risk for revision surgery with a hazard ratio of 2.23 (CI 95% 1.69–2.88) and postoperative infection of 2.85 (1.97–3.98) [11]. These cases are technically more demanding, but patients can have good outcomes if appropriate limb alignment and implant positioning are achieved [12].

Primary Arthroplasty for Elderly Patients with Acute Comminuted Distal Femur Fractures

In the elderly and frail patient population, the 1-year mortality rate has been reported to be 22% after sustaining a supracondylar femur fracture. This older study went on to further report that 9% of patients needed an above-knee amputation at a later time point due to loss of fracture reduction and/or infection [13]. Due to this suboptimal outcome, over the last couple decades several case series on the use of primary TKA or distal femoral replacement for distal femur fractures have been published. The goal was that an immediate arthroplasty would allow immediate weight bearing and allow patients to regain mobility faster with the theory that they will have fewer complications.

One case series did not demonstrate any improvement in mortality rate and reported a 1-year mortality rate of 30%. They did find a revision rate of 9.5% which is better than reports of complication rates up to 25% for primary TKA for posttraumatic osteoarthritis [14].

Malviya et al. examined the use of acute primary TKA for periarticular distal femur and proximal tibia fractures. They reported that 10 of the 11 distal femur fractures were treated with a rotating hinge, and one was treated with a varus/valgus constrained implant and that they had good clinical outcomes in their case series [15]. Bettin et al. reported on 18 patients who had sustained comminuted intraarticular, osteoporotic, arthritic fractures and were treated with cemented distal femoral replacements. They had two patients who had complications with their implants (one periprosthetic fracture and one deep infection). They reported that the patients in their series were extremely or very satisfied with their outcomes but did not have a comparison arm [16]. Rosen and Strauss reported their use of distal femur replacements in a case series of 24 patients for distal femur fractures and found 71% returned to their preoperative ambulation level [17].

As of now only one retrospective comparative study of ORIF with distal femur replacement has been reported by Hart et al. They found that at 1-year follow-up all the distal femur replacement patients were ambulating while 25% of the ORIF patients were wheelchair bound, but this was not statistically significant. They found comparable reoperation rates of 10% in the distal femur replacement group and 11% in the ORIF group. The ORIF group had fractures healed at an average of 24 weeks but had a nonunion incidence of 18% [18]. Due to the relative rarity of converting a distal femur ORIF to TKA, Bohm et al. suggested that ORIF should be used in most acute fracture cases. However, for specific patient populations with prior arthritis, not compliant with weight-bearing restrictions, and very comminuted fractures, a primary arthroplasty could be considered [19].

One of the surgical considerations for treating acute fractures is that higher levels of constraint such as a rotating hinge prosthesis may be necessary since there is a higher likelihood that the collateral ligaments are compromised by the fracture. In order to determine the joint line in a highly comminuted fracture, one method that can be used in acute fractures is obtaining a temporary reduction with the use of an external fixator or other methods. Alternatively, the joint line can be determined relative to anatomic landmarks such as 1 cm proximal to the fibular head or 2.5 cm distal to the femoral epicondyles (based on their reduced position). Sizing the femur in an acute fracture may be difficult, and estimates based on the trials may be needed. In addition, depending on the level of bone loss/comminution, augments, wedges, sleeves, or cones may be needed [20].

When acute fractures with severe comminution of the condyles are treated with arthroplasty, then a distal femoral replacement may be needed. Some of the technical challenges are to determine the length and rotation of the femur. This can be accomplished by obtaining provisional reduction with traction and from there the rotation can be determined based on the transepicondylar axis. Another consideration is whether to press-fit or cement the stem. Given the likely poor bone quality, the stem will likely need to be cemented [19]. Arthroplasty can be more challenging in these cases but focusing on proper alignment, positioning, and fixation can lead to good patient outcomes.

Surgical Considerations at Arthroplasty for Posttraumatic Arthritis

When comparing posttraumatic arthritis to osteoarthritis for the etiology for TKA, it has been reported that TKA takes about 30 minutes longer in the posttraumatic case [21]. Extensor mechanism issues are a common source of difficulty in performing these procedures. Lateral release was needed in 47% of TKAs reported by Weiss et al. [12] and 46% for Papadopoulos et al. [22]. Other techniques that needed to be used were quadriceps V-Y turndown, vastus medialis advancement, LCL transfer, extensor mechanism realignment, and collateral ligament reconstruction [12, 22].

One of the first considerations for performing a total knee arthroplasty is determining the level of constraint needed. The next step is determining the joint line and component rotation. If the fracture has healed in appropriate alignment and rotation, then standard techniques can be used. However, in cases of deformity or retained hardware that would prevent or severely complicate intramedullary alignment, patient-specific instrumentation, imageless hand-held navigation devices, or computer navigation can be very helpful to establish the alignment.

For larger bony defects, structural allograft or metal augments can be used. Prior hardware and whether it will interfere with the procedure needs to be considered, and the prior hardware can be appropriately removed or retained [12].

Limb alignment needs to be evaluated and malalignment needs to be corrected with intraarticular resections for an arthroplasty or staged/simultaneous osteotomy. If intraarticular resections would compromise the collateral ligaments in order to obtain the necessary alignment correction, a distal femoral osteotomy can be secured with a long-stem femoral component or staged with a plate and screw construct. Bone graft can be placed at osteotomy and nonunion sites [12]. Papadopoulos et al. reported a case series of 48 TKA after distal femoral fractures and found malunions greater than 10 degrees in the coronal plane or 15 degrees in the sagittal plane in 21 knees (44%). Of these with malunions, they were able to correct 15 through intraarticular bony resections and 6 needed osteotomies [22].

Case Example of Staged Osteotomy

A 53-year-old male with a history of a supracondylar left femur fracture treated nonoperatively 35 years ago presented to the clinic with symptomatic left knee pain (Fig. 10.1).

Fig. 10.1 (**a**–**c**) Preoperative lower extremity alignment and AP/lateral distal femur

Options to address the deformity would be to perform an intraarticular correction with a TKA or an extraarticular correction with TKA. In the case of the extraarticular correction, the osteotomy could be performed in staged or simultaneous settings. In this case, templating for an intraarticular resection demonstrates that there would be a risk of compromising the MCL origin (Fig. 10.2). Consequently, it was decided to perform an extraarticular correction of the deformity, and it was done in a staged setting.

For this patient a lateral opening wedge osteotomy of the distal femur was planned and performed (Figs. 10.3 and 10.4).

Five months after surgery the osteotomy site had healed (Fig. 10.5).

Fig. 10.2 Templating for intraarticular resection

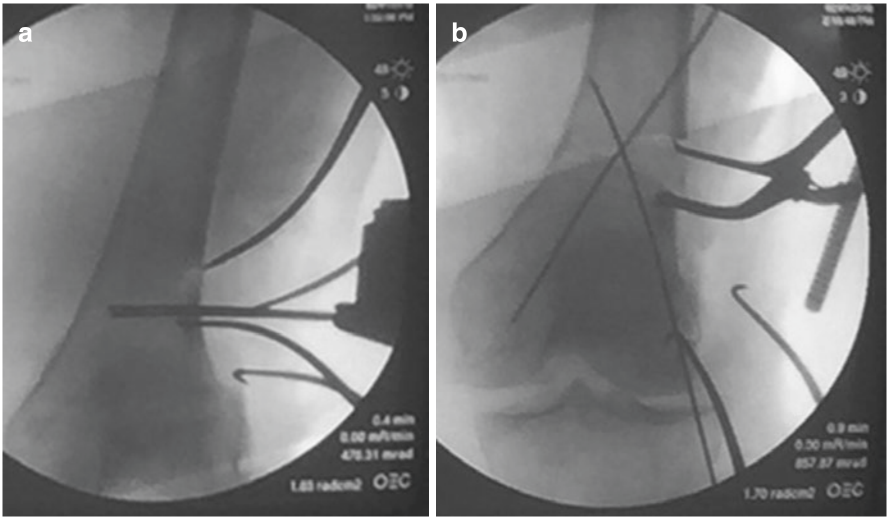

Fig. 10.3 (**a**) Intraoperative fluoroscopy picture after the osteotomy was performed; (**b**) change in alignment after insertion of the bone graft wedge with provisional fixation

Fig. 10.4 Postoperative picture of the patient's lower extremity

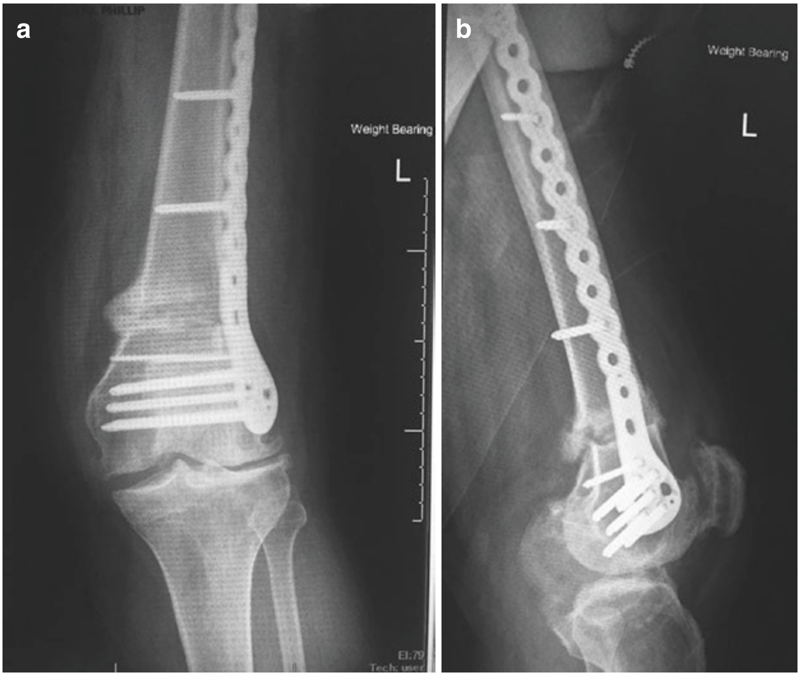

Fig. 10.5 (**a**, **b**) AP and lateral X-rays at 5 months after healing of osteotomy

Case Example of Intraarticular Correction of Deformity and TKA

A 60-year-old male with history of a nonoperatively managed femur 45 years ago presents with advanced arthritic changes of his knee and instability of his knee (Figs. 10.6 and 10.7).

Preoperative templating plans for planned resections demonstrated that the correction could be obtained through intraarticular osteotomies with the TKA (Fig. 10.8).

For this patient, given the malunion in his femur, a long intramedullary femoral alignment rod could not be used and instead a short rod was used. A 3-degree valgus distal femoral cut was performed as templated. Next the tibial cut was performed with intramedullary referencing and then extension space balancing was performed. Preoperatively there was concern that the MCL was incompetent, and the surgeons were prepared to perform a rotating hinge total knee arthroplasty. Intraoperative evaluation determined that the MCL was still intact and as a result extension space balancing was performed. After release of the posterolateral capsule and pie-crusting of the IT band and LCL, the gaps were within 3–4 mm of each other.

Fig. 10.6 Clinical picture of the deformity

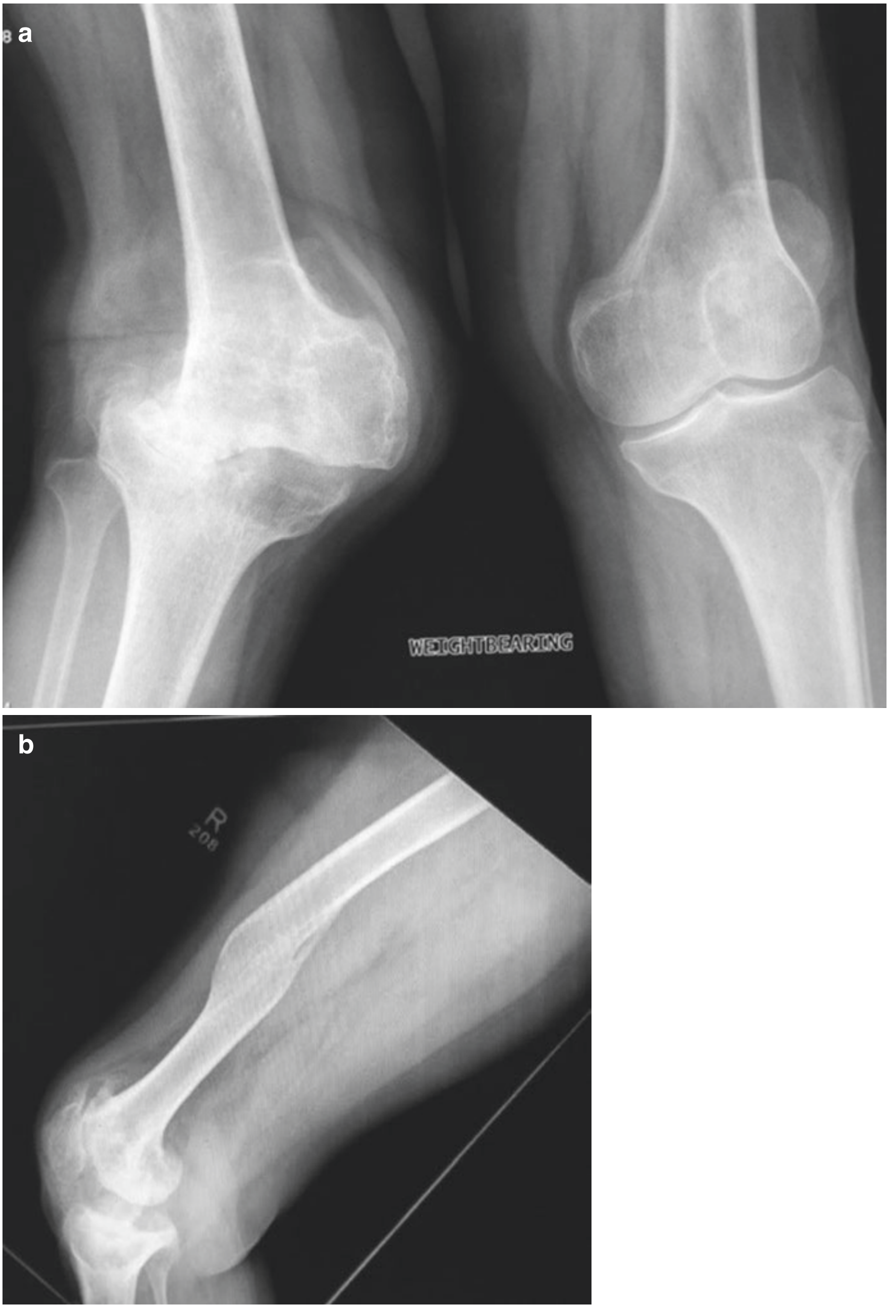

Fig. 10.7 (**a**, **b**) AP and lateral of his knee demonstrating the extraarticular deformity with advanced osteoarthritis and significant coronal plane malunion

Fig. 10.8 Preoperative templating for intraarticular correction of deformity

Femoral rotation was determined by flexing the knee to 90 degrees and aligning the femoral cutting block with the tibial cut. Preoperative templating determined that a 100 mm sleeve-stem length could be used on the femoral side without reaching the site of malunion. A varus-valgus constrained implant was used, and a stable knee was achieved with good patellar tracking (Figs. 10.9 and 10.10).

Fig. 10.9 Clinical picture of leg after surgery

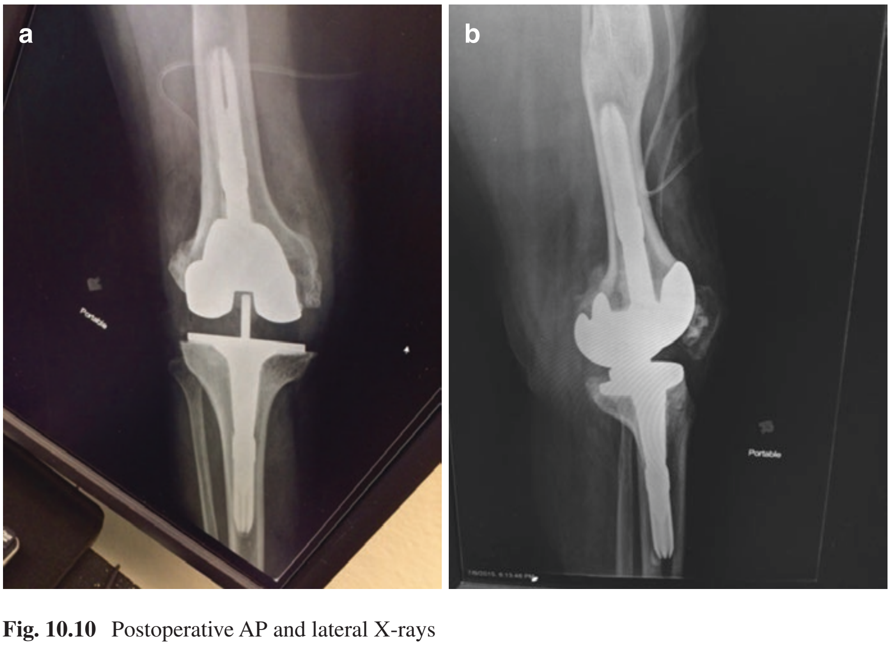

Fig. 10.10 Postoperative AP and lateral X-rays

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Chapter 11
Post-traumatic Arthritis of the Proximal Tibia

Stefanie Hirsiger, Lukas Clerc, and Hermes H. Miozzari

Key Points

- Although tibial plateau fractures are not rare, symptomatic posttraumatic osteoarthritis is rather infrequent.
- Stepwise treatment algorithms should be followed, starting with activity modification, weight loss and physiotherapy, followed by analgesic medication.
- Existing literature concerning operative treatment options for posttraumatic osteoarthritis is mainly limited to small case series with little evidence.
- Corrective osteotomies should be evaluated; if degenerative lesions are too advanced, unicondylar or total knee replacement can ameliorate function.

Introduction

Posttraumatic osteoarthritis (OA) occurring after tibial plateau fractures is more rarely encountered than primary OA. The overall disease burden of posttraumatic OA is estimated to be 12% of all symptomatic OA of the hip, knee, and ankle [1] with 1.2% incidence in the proximal tibia [2]. The last is mostly seen during the fifth decade and secondary to fall from heights or motor vehicle accidents [3]. The complexity of the fracture correlates to the bone quality and the mechanism of injury.

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_11

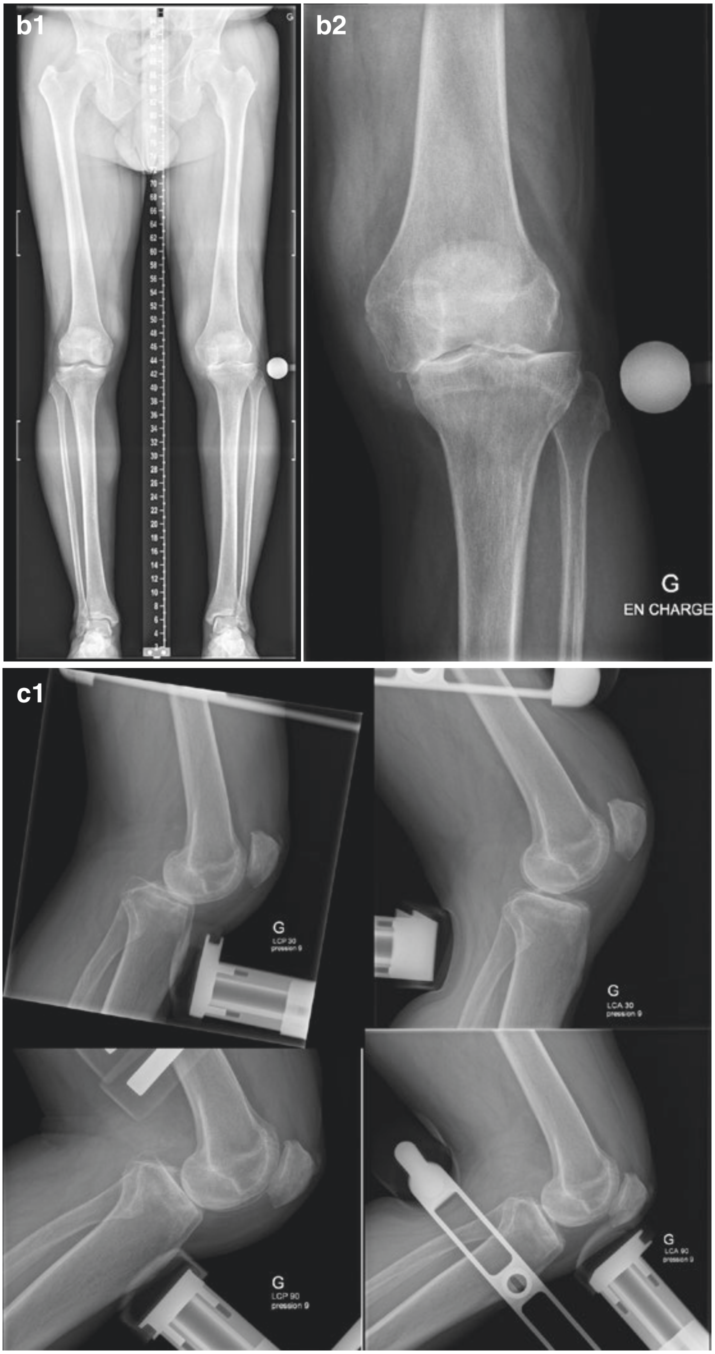
Despite several classification systems being available, such as Schatzker [4] or the AO [5], which are based on bony and intraarticular landmarks, none of them are complete or have a direct implication on the surgical treatment. Most tibial plateau fractures are treated operatively. There is only sparse literature defining clear criteria for the indication of surgical treatment. According to older literature, every medial unicondylar fracture (with any displacement) and every medially tilted bicondylar fracture should be operated as well as lateral plateau fractures with a lateral tilt or valgus malalignment exceeding 5°, a displacement with condylar widening of more than 5 mm, and step-offs greater than 3 mm [6]. A recent review found no consensus about the acceptance for any residual articular step-offs after reduction, but in comparison to other joints they seem relatively well tolerated [7]. Posterior fractures, present in about 29% of all Schatzker fracture types [8], are often missed with conventional radiographs; thus CT imaging is recommended for surgical planning [9]. More recently, a three-column concept for classification and fixation has been proposed [10]. The medial, lateral, and posterior columns are evaluated for intra- and extraarticular cortical disruption on 2D and 3D reconstructed CT images. In this updated concept the mechanism of injury is considered and evaluated by analyzing the position of the knee and the direction of the deforming forces at the time of injury: by defining the key articular surface, both the articular approach and hardware to be used can be planned before surgery [11]. The incidence of concomitant soft-tissue injuries has been found to be almost 100% when interpreting acute knee MRI [12]. Meniscal injuries are seen most frequently, followed closely by cruciate- or collateral ligament ruptures but also predating injuries such as asymptomatic meniscal changes with diffuse edema [12]. Unrecognized, chronic ligamentous instability without associate fracture is a major issue that can lead to symptomatic knee OA (Fig. 11.1) [13]. Further, untreated anterior ligament rupture shows associated secondary meniscal ruptures of up to 100% at 10 years [14]. Although there is no hard evidence that the surgical treatment of ligamentous instability can prevent developing symptomatic OA [15], meniscal and ligamentous injuries can lead to instability and persisting pain [16]. They should, therefore, be diagnosed and addressed during osteosynthesis, and an arthroscopically assisted approach might be helpful in these cases [17].

Injured soft tissues along with open wounds can lead to discontinuity of the cutaneous barrier, resulting in soft tissue infections and/or compartment syndrome. Thus, not only the bony and intraarticular damage but also the surrounding soft tissue status should be considered for surgical planning [18]. The optimal treatment of such complex injuries must be individualized, taking into account patients' factors, such as comorbidities, activity level, bone quality, and the presence of predating OA. Surgical options range from conservative treatment to closed/open fracture reduction with either internal or external fixation, or even primary prosthetic replacement in selected cases [19, 20].

Long-term outcomes after tibial plateau fractures are associated with the development of secondary OA. The initial injury and the extent of bony, cartilaginous and soft tissue destruction are crucial to determine the risk of future OA [21]. Indeed, the incidence of OA rises with the complexity of the fracture [22] and is further increased by secondary posttraumatic changes such as an altered limb axis, axis load distribution, or ligamentous instability [23, 24]. Smoking is an independent risk factor for a secondary conversion to a joint replacement procedure [25]. As of today, there is still no consensus in the literature of what is considered an acceptable residual postoperative deformity. However, a persistent postoperative valgus malalignment >5° and articular step-off of more than 2 mm have been shown to be risk factors for early OA and poor outcomes in older patients [23, 26] with degenerative changes appearing between 2 and 11 years after trauma (mean 7 years) and an incidence of posttraumatic OA, based on radiographies, reported between 25% and 45% [27]. Nevertheless, in retrospective analyses, the rate of symptomatic OA ranges only from 2% to 7.5% [24, 25, 28] with major reconstructive surgery needed in 4–7% at 10 years follow-up [27].

Recent developments in imaging allow the quantitative and qualitative evaluation of posttraumatic cartilage defects [29]. Genetic and environmental factors also play an important role in the development of posttraumatic OA [13].

Fig. 11.1 60-year-old patient who sustained a stairway fall with concomitant ACL/PCL/MCL rupture and a nondisplaced fracture of the medial compartment (tibia and femur condyle). The patient presented after 5 months at our office; standard X-rays show a secondary OA mostly involving the medial compartment with joint space narrowing and bone loss, along with ACL and PCL laxity. (**a**) Initial MRI sagittal image: anterior and posterior cruciate rupture visible. (**b**) Long axes (**b**1) and knee anterior-posterior (**b**2) after 5 months showing subluxation and OA of the medial compartment with beginning tibial bone loss. (**c**) Stress X-rays: (**c**1) anterior and posterior drawer and (**c**2) varus and valgus stress. (**d**) Postop X-rays after a primary PS TKA anteroposterior (**d**1) and lateral (**d**2). The MCL and LCL were intact



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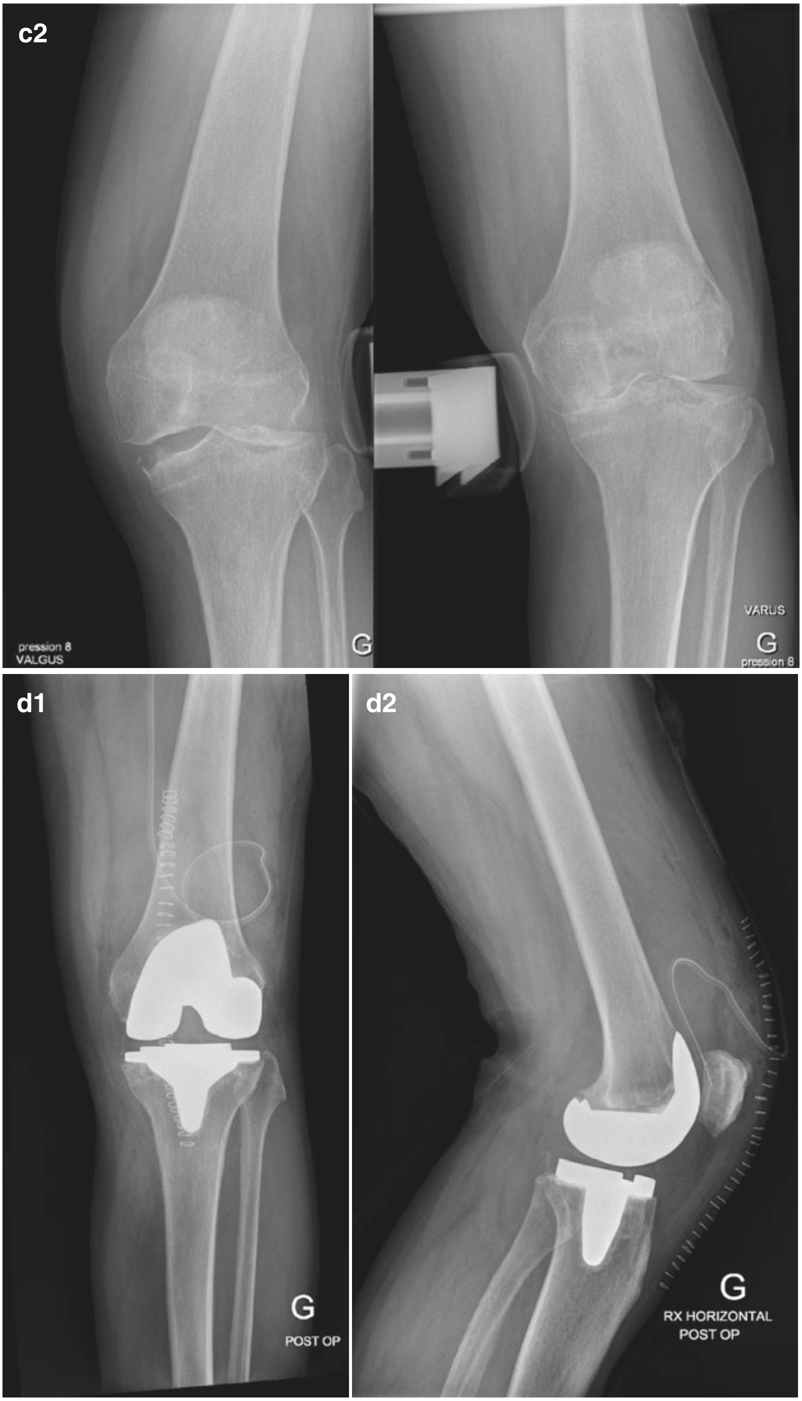

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Conservative Treatment for Posttraumatic OA

A stepwise medical treatment is paramount in symptomatic knee OA, regardless of its origin. Recently, a consensus statement on the algorithm of the European Society for Clinical and Economic Aspects of Osteoporosis and Osteoarthritis (ESCEO) has been published [30]. Paracetamol (Acetaminophen), despite its minimal efficacy for OA symptoms, is still largely used due to its low cost and presumed safety, but, with higher dosage (>3 g/day), there is evidence of increased risk of upper gastrointestinal events, severe liver damage, loss of renal function, and increase in hypertension [30]. NSAIDs appear to be more effective, but comorbidities and risk of adverse effects have to be taken into account [31]. Topical NSAIDs seem to have an equivalent effect to oral NSAIDs for knee pain with fewer adverse events and 40% less need for concomitant oral administration. Therefore, they may be preferred for geriatric patients, patients at increased risk for gastrointestinal bleed, and those with cardiovascular or renal problems [30]. If NSAIDs are contraindicated, tramadol can be used to provide pain relief [32]. Despite weak evidence, chondroitin sulfate can lead to clinical improvement [33], and short-time beneficial effects of several weeks to months can be obtained with intraarticular infiltrations with corticosteroids [34]. Though widely used, intraarticular viscosupplementation does not provide sufficient evidence for benefit, and it is not recommended by the international osteoarthritis research society (IOARS) [35]. The interest in biologic treatment such as intraarticular platelet-rich plasma and mesenchymal stem cells (bone marrow-, adipose-, and amnion-derived) is growing, but a recent review of the published literature highlights the necessity for larger studies with a higher level of evidence and more standardized protocols [36]. The role of physiotherapy is still debated [37, 38] but seems to be moderately effective for improved function and, with some reservation, for pain [39]. Aquatic exercises may as well have small, short-term and clinically relevant effects on pain, disability and quality of life, though with moderate quality evidence [40]. Adapting activities is important, and there are a number of recreational activities of moderate intensity recommended for OA patients such as swimming, cycling, yoga, tai-chi, and walking. The latter, one of the simplest forms of exercise, has a positive effect on symptomatic knee OA [41], especially when associated with an intensive diet [42]. The role of running in developing knee OA is not clear [43], and some authors advocate a potential protective effect [44]. A prospective control study over two decades in middle- to older-aged long-distance runners could not show any evidence of accelerated OA [45]. In patients with painful OA, on the other hand, high intensity activities such as running, football, Nordic skiing, water skiing, handball, and basketball should be avoided [44]. Weight reduction can have a positive effect on pain and reduce disability in obese patients [46]. A recent study showed that high levels of synovial joint leptine may affect joint pain and might explain the association of pain with female gender and obesity, but the mechanism is not obvious and the causal relationship has yet to be proven [47].

Surgical Treatment for Posttraumatic OA

If conservative treatment proves insufficient to obtain an acceptable function and quality of life for the patient, the evaluation of a surgical treatment deems necessary.

No evidence for a beneficial effect was found for arthroscopic procedures and are, thus, not recommended [48]. Osteotomies can be used in order to diminish load on the degenerative compartment. Other options include osteochondral allografts and, as a last resort, partial or total knee arthroplasty (TKA) [25]. Surgery should be individually adapted; the options will be discussed subsequently.

Osteotomies

Correction osteotomies are a widely used treatment method to address early OA related to deformities of the leg axis and/or ligamentous instability [49]. This conservative technique allows good middle-term outcomes in a majority of patients delaying the time to total knee arthroplasty but is correlated to a relatively high rate of complications of up to 31% [50]. Preliminary results and operative technique of correction of intra- and extraarticular malunion after tibial plateau fractures have been described in case series [51–53]. The proposed intraarticular osteotomies aim at restoring joint anatomy and therefore stability, thus potentially slowing OA development. Knee OA combined with complex extraarticular deformities can be addressed by osteotomy and gradual computer-guided correction with a multiplanar external fixator such as the hexapod [54] (Fig. 11.2).

Osteochondral Allografts

Osteochondral allografts (OCA) could be a valuable alternative to prolong the prosthesis-free lifetime by preserving the joint. The survival of TKA is limited, indeed, especially in young and active patients, with a significantly higher failure within the first 2 years after implantation in the posttraumatic setting [55]. Still, reports about OCA to treat posttraumatic tibial OA remain sparse, showing good outcomes in active patients [56] and a clear improvement of postoperative function, which is also superior to microfracturing [57]. Kaplan-Meier survivorship analysis showed that the survival rate was 95% at 5 years, 80% at 10 years, 65% at 15 years, and 46% at 20 years [58]. Although almost half of the patient needed a conversion to TKA eventually, the mean time to conversion was 12 years [58].

Unicompartmental Knee Arthroplasty

Posttraumatic OA after tibial plateau fractures can be limited to one compartment. If symptomatic and in the absence of metaphyseal deformity, a correction osteotomy should not be considered, unless for a young patient, as it would add to the existing intraarticular pathology an extra axis deformity between the knee and the ankle joint line [59]. In this situation, a unicompartmental knee arthroplasty (UKA) might be considered. Although long-term-survival is lower and, thus, revision rates are potentially higher in UKA compared with total knee prosthesis (TKA) [60], faster rehabilitation, better knee kinematics, and lower complication rate [61] can be advantageous for both relatively young, active patients [62] and the elderly [63]. Since patients with posttraumatic OA needing surgery tend to be younger than for primary OA, this point is relevant [64]. The literature addressing the outcome in posttraumatic OA is sparse. In primary OA, 10 years survival of 95% has been reported for medial UKA [65, 66] and 92% for lateral, diminishing to 84% at 16 years [67]. Sah and Scott compared the results in a small series for lateral UKA used in posttraumatic (10 patients) versus primary OA (38 patients) [64, 68]. The Knee Society knee and function scores (KSS) were significantly lower in the posttraumatic group, with 74 and 65, respectively, versus 95 and 86 in the group for primary OA. More recently, Lustig et al. showed better results for a retrospective series of 13 lateral UKA in the posttraumatic setting, with implant survivorship of 100% at 5 and 10 years and 80% at 15 years along with function and pain relief comparable to primary OA with a KSS score of 89 and 87 for function [64]. We are not aware of studies comparing outcomes of UKA versus TKA for posttraumatic OA. Intraoperative conversion from a scheduled lateral UKA to TKA after evaluation of the neighbor compartments was reported in 52% of the patients [68]. For this reason, the authors advise the use of a medial parapatellar approach, and patients should be informed of a potential conversion to TKA for consent. Alternatively, a lateral parapatellar approach can be used and would easily allow a conversion to TKA.

Total Knee Arthroplasty

In advanced tricompartmental OA, when impairment of knee function and quality of life are important and conservative measures have failed, TKA can be indicated. Compared to a normal population, 10 years after tibial plateau fracture, patients are 5.3 times more likely to need a TKA [24]. The need increases with increasing age (per year over 48), bicondylar fracture pattern, and greater comorbidities [24]. Patients with instability or nonunion of the proximal tibia need TKA earlier than those with malunions (13.3 and 14 vs. 50 months), with a higher incidence of complications [69], such as wound problems, deep infection, patellar tendon avulsion, and reduced range of motion [1, 27]. Outcomes are further diminished in the

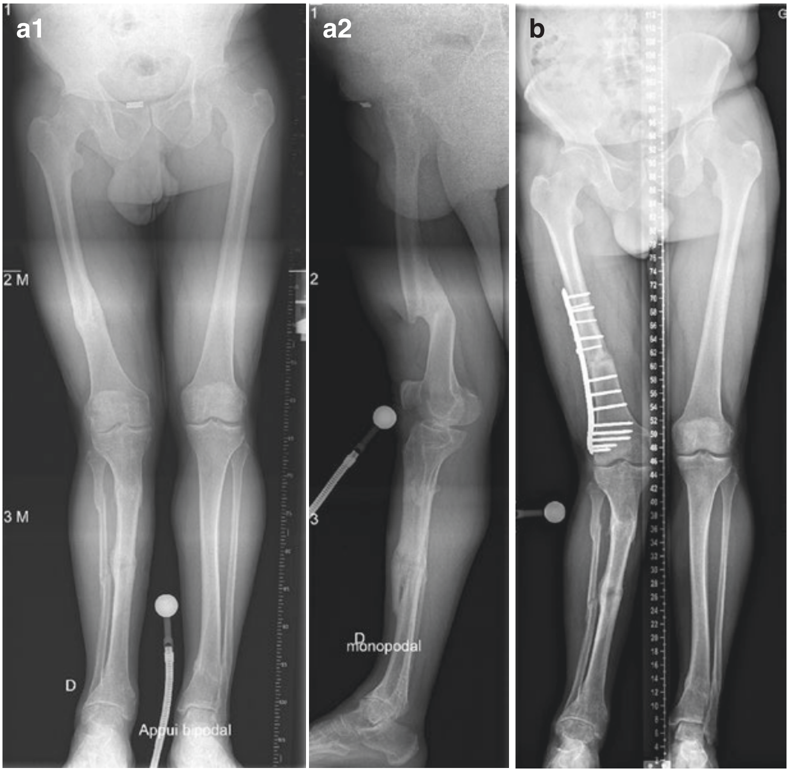
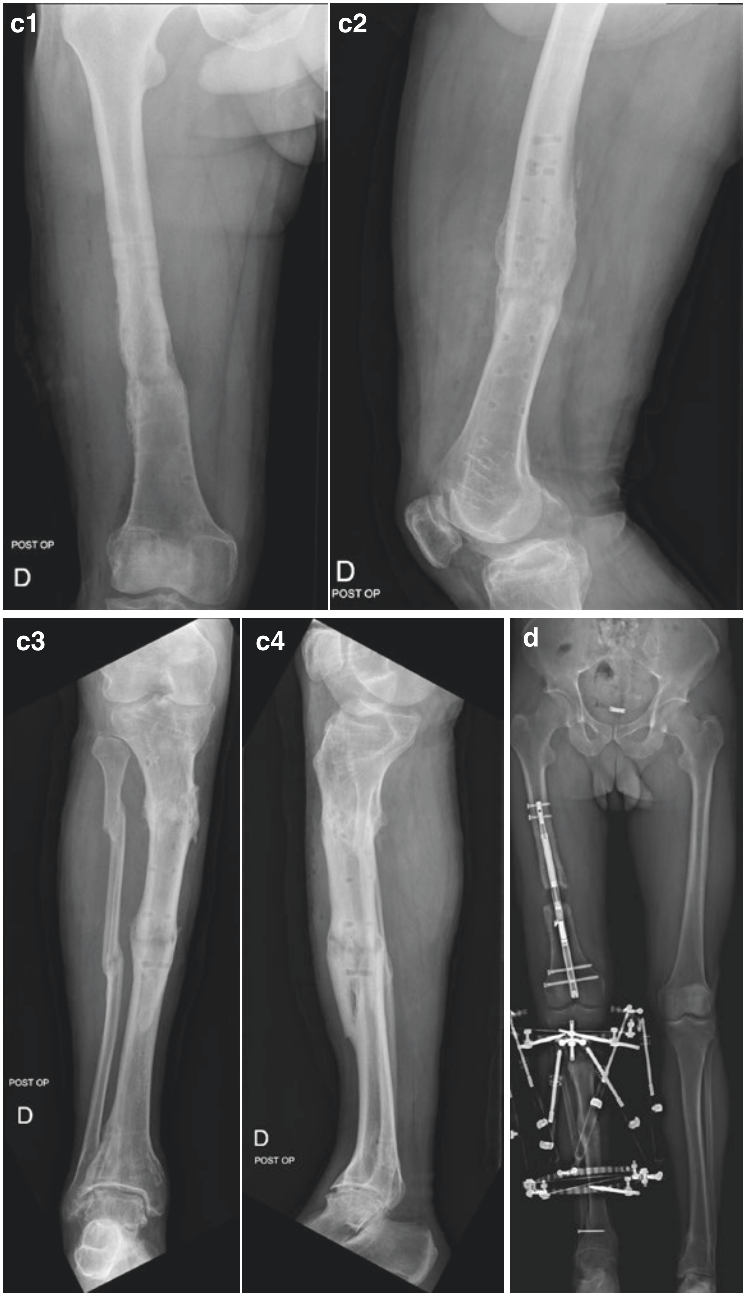


Fig. 11.2 46-year-old patient with a status post three motor vehicle accidents. At age 17 he sustained an open fracture (unknown open grade) of the right femoral diaphysis, treated with transtibial traction. At 18 he had an open fracture of the right tibia and fibula (unknown open grade) also treated nonoperatively. At the age of 43 he sustained a new open fracture Gustilo II of the right tibia and fibula, treated with intramedullary nail fixation despite the preexisting malunion. The fracture healed uneventfully, and the nail was removed after 2 years. The patient presented with worsening right knee pain 1 year later, corresponding to a symptomatic lateral OA with gait disturbance due to a complex valgus deformity of the lower right leg (shortening 5 cm, recurvatum 17°, valgus 11°, tibial slope 15°, external rotation 38°). Decision was made to perform a dual femoral and tibio-fibula distraction osteotomy with computer-guided correction using multiplanar external fixator for the tibia and distraction nail for the femur. (**a**) Long leg axis showing the different deformities of the right side ap (**a**1) and sagittal plane (**a**2). (**b**) Long leg axis after corrective femoral osteotomy for a preexisting recurvatum malunion of 17°. A tibial osteotomy was made thereafter without complete correction of the deformity. (**c**) Status post removal of hardware, femur ap (**c**1) and lateral views (**c**2), tibia ap (**c**3), and lateral (**c**4) (**d**) Long leg axis (EOS) at 4 weeks after femoral osteotomy (deflexion, slight varisation, and lengthening) with retrograde expandable nail, and tibia/fibula osteotomy (varisation and translation and slight lengthening) and fixation with hexapod. (**e**) Long leg axis (EOS) after removal of the hexapod at 3.5 months, ap (**e**1) and lateral (**e**2) views. The whole axis has a slight residual valgus, the tibia has healed, and the callotaxis after femoral osteotomy is partially consolidated. (**f**) Long leg axis after healing of the femoral callotaxis before nail removal. The patient is still suffering from lateral OA but correction of the axis did improve the situation and arthroplasty has been delayed



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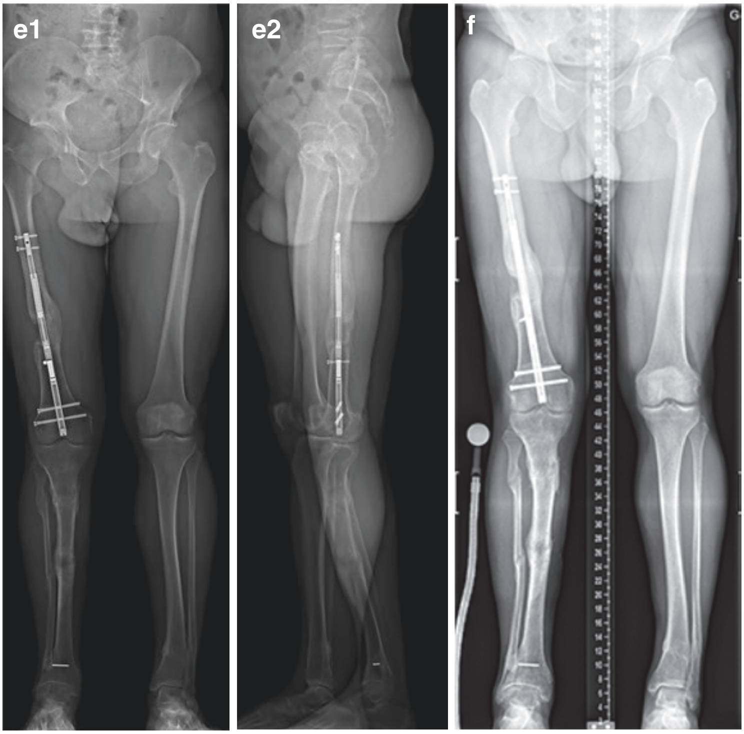

Fig. 11.2 (continued)

presence of combined secondary tibial and femoral deformities or soft tissue compromise [70], resulting in technically more demanding surgeries with extended operative time [71], increased length of stay, and 30-day readmission [72]. Abdel et al. reported a high rate of complications in TKA for posttraumatic OA (34%) compared to primary OA, 90% occurring within the first 2 years [73]. Houdek et al., in a larger retrospective cohort from the same institution, reported an overall revision-free survival of 78% at 15 and 20 years of follow-up with a significant risk for revision in patient aged 60 or less as well as patients with an infection, hematoma, deep vein thrombosis, or pulmonary embolism following arthroplasty [74]. Objective and subjective outcomes rely on sparse literature on (obviously) relatively small series, showing comparable KSS [73], Patient-Reported Outcome Measurements (PROMs), and satisfaction [69, 75]. In the existing studies, implants with different degrees of constraint have been used, from cruciate-retaining to hinge models with or without tibial augments and a long stem [20, 75–77]. Indeed, the type of prosthesis should be adapted to ligamentous stability, bone stock, and bone quality [78].

Primary TKA in the acute setting has been proposed in selected cases of complex fractures in osteoporotic bones of elderly patients; experiences are limited to small case series, but the results are promising [77, 79–82]. Of importance, autonomy in the elderly population is reduced after tibial plateau fractures even when TKA is done in first intention [83]. Additionally, age is an independent risk factor for mortality within 30 days after TKA [84].

Summary

In everyday practice, symptomatic knee OA secondary to tibial plateau fractures is relatively rare. Radiologic incidences varies between 25% and 45% with major reconstructive surgery reported to be needed in only 4–7% at 10 years follow-up [24, 27, 28]. Risk factors for the development of symptomatic OA are complexity of the fracture [22], concomitant intra- and extraarticular soft tissue injury [18], the age of the patient at the time of injury [23], persistent postoperative valgus malalignment >5°, and a persistent articular depression >2 mm [23] or ligamentous instability [24] as well as smoking [25]. When OA becomes symptomatic, a stepwise medical treatment is paramount [30] and activity modification should be addressed at first: moderate activities such as walking have a positive effect on symptomatic knee OA [41], whereas high-level activities should be avoided [44]. Weight reduction can reduce pain and thus improve disability in obese patients [46]. The role of physiotherapy and aquatic exercise is still debated, but given the few side effects, it is recommended [37–40]. Paracetamol (acetaminophen) is still widely used, even though symptom relief is minimal and side effects not infrequent [30], and NSAIDs appear to be more effective [31]. Given the equivalent effect of oral and topical NSAIDs applications, the latter should be preferred to reduce adverse events [30]. Intraarticular infiltrations with corticosteroids can temporarily reduce symptoms [34]. Chondroitin and tramadol can provide some pain relief [30, 32, 33]. When conservative treatment becomes insufficient, surgical treatment must be considered. Especially in young patients, a conservative, joint-preserving surgery should be prioritized whenever possible. Osteotomies have been described for the correction of intra- and extraarticular posttraumatic deformities [51–53]. If OA is too advanced and without extraarticular deformities, unilateral knee arthroplasty (UKA) can be an option. The revision rate is higher in UKA than in TKA [60], but faster rehabilitation, a better knee kinematics, and lower complication rates [61] can be advantageous especially for young, active patients [62]. Good results with implant survivorship of 100% at 5 and 10 years and 80% at 15 years, and good knee function are described [64, 68]. Fifty-two percent of conversions during surgery, from UKA to TKA, after evaluation of the neighbor compartments have been reported [68]. For severe, generalized OA, TKA is preferred. The type of implant constraint can range from cruciate-retaining to posterior-stabilized and up to hinge models with or without augments and a long stem, depending on ligamentous stability, bone stock, and bone quality [20, 75–78]. Compared to TKA for primary OA, the risk for complications is higher in the posttraumatic setting, and surgery is likely to be more complex [1, 27, 70, 71, 73]. Still, even if revision rates are higher [74], PROMs and patient satisfaction are comparable [69, 75]. Primary TKA in the acute fracture setting has been proposed in selected cases of complex fractures in osteoporotic bone of elderly patients, but experiences are limited to small case series [77, 79].

Despite injury prevention, future research should aim at reducing the development of postoperative OA. Sclerostin has been found to play a role in cartilage degeneration in mice [85, 86]. When applied intraarticularly or if upregulated transgenically, it plays a protective role, maintaining cartilage integrity, while its loss promotes osteoarthritis [85, 86]. If such approaches would prove to be safe and effective in humans, pain and functional impairment and, consequently, the need for arthroplasties could eventually be prevented by modification of the degenerative cascade.

Conflict of Interest All authors declare that they have no conflict of interest to disclose and have not received external funding.

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Chapter 12
Post-traumatic Arthritis of the Ankle

Nigel N. Hsu and Lew Schon

Key Points

- The ankle joint is more susceptible to posttraumatic arthritis than the hip or the knee joint.
- Ankle biomechanics play a major role in posttraumatic arthritis.
- Weight-bearing CT scans are new imaging modalities to help with the diagnosis and management of posttraumatic ankle arthritis.
- The mainstay of surgical treatment is total ankle arthroplasty and ankle arthrodesis.

Introduction

Posttraumatic osteoarthritis accounts for 12% of arthritis across all joints, which represents 5.6 million people, and cost the US health care 3.06 billion dollars annually [1]. For the ankle joint, posttraumatic arthritis is the primary cause of arthritis accounting for 70–79.5% of ankle arthritis [1, 2] compared to 1.6% in the hip and 9.8% in the knee. This variation is due to the mechanical, biochemical, and anatomical factors of the ankle. Although the prevalence of ankle osteoarthritis is about 9 times lower than that of the knee and hip [3], in 2010, approximately 4400 total ankle replacements and 25,000 ankle fusions were performed in the United States [4]. Fifty percent of elderly patients have some form of arthrosis of the foot or ankle [5].

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_12

In this chapter, we will examine the pathophysiology and biomechanics of posttraumatic ankle arthritis and review indications and nonoperative and operative treatment options.

Anatomy

Primary osteoarthritis of the ankle is less common compared to the knee and hip due to its anatomy and biochemical factors. The bony anatomy of the ankle joint confers a high degree of stability and congruence when the joint is loaded [6]. The bony anatomy, ligaments, and joint capsule guide and restrain movement between the talus and the mortise. There is minimal translation of the talus relative to the mortise during normal motion due to the soft tissue around the ankle.

Although the ankle has a smaller area of contact between articular surfaces compared to the hip and knee (350 mm^2 at 500 N of load compared to 1100 mm^2 for the hip and 1120 mm^2 for the knee) [7–9], the tensile fracture stress and tensile stiffness of ankle articular cartilage deteriorate less rapidly with age than those of the hip [10]. The articular cartilage of the ankle is 1–2 mm compared to the articular cartilage in the hip and knee, which is 3–6 mm [11, 12]. The metabolism of cartilage degradation is also different between the ankle and that of the knee. The catabolic cytokine interleukin-1 (IL-1) inhibits proteoglycan synthesis of chondrocytes more in the knee than the ankle, and this is in part due to fewer IL-1 receptors in the ankle articular chondrocyte [3].

The high peak contact stress from smaller contact area, the congruency of the joint, and thinness of ankle articular cartilage make the ankle joint more susceptible to posttraumatic osteoarthritis than the hip and knee. Injuries that damage the joint congruency and articular cartilage lead to joint degeneration within 2 years of injury [6]. Newer studies have found that posttraumatic osteoarthritis can occur after ankle fracture despite anatomic reduction [13], and early inflammatory response could lead to irreversible damage to the cartilage [14]. The synovial fluid analysis showed that after intraarticular ankle fracture, there is a proinflammatory and extracellular matrix degrading environment similar to that described in idiopathic osteoarthritis. Specifically IL-6, IL-8, MMP-1, MMP-2, MMP-3, MMP-9, and MMP-10 were significantly elevated compared to normal synovial fluid [15].

Epidemiology

Trauma and abnormal ankle biomechanics are the most common causes of degenerative changes [16]. Traumatic injuries of the ankle include malleolar fractures, pilon fracture, talus fracture, fracture dislocations, osteochondritis dessicans, ankle sprains, and instability. The most common causes of posttraumatic ankle arthritis are rotational ankle fractures (37%), recurrent ankle instability (14.6%), and single sprain with continued pain (13.7%) [2]. The severity of ankle fractures is correlated to the development of posttraumatic ankle arthritis. Lindsjo reported that the prevalence of ankle arthritis is 14% after ankle fractures and ranges from 4% in Weber A to 33% in Weber C fractures [17]. Pilon fracture of the tibial plafond is a high-energy injury that causes significant morbidity. Posttraumatic osteoarthritis after pilon fracture is 26.6% [18]. Talus fracture is associated with both subtalar and tibiotalar posttraumatic osteoarthritis. The rate of arthritis after talar fracture is 47–97% [19].

Patient Evaluation

History and physical examination are essential in diagnosing posttraumatic osteoarthritis. Determining a history of trauma such as a fracture, ankle sprain, or instability episode can help with diagnosing posttraumatic osteoarthritis of the ankle. Careful examination of the ankle in sitting, standing, and walking is helpful. Examine the range of motion, stability of the soft tissue, and alignment, and deformity of the foot and ankle should be evaluated as well as gait to see the effects of proximal or distal pathology. Plain weight-bearing radiographs of the ankle should be obtained. The hindfoot alignment view is important to evaluate the hindfoot deformity. Computed tomography (CT) can be useful to assess bony issues such as malalignments, cysts, malunions, and nonunions. Magnetic resonance imaging (MRI) is useful for evaluating cartilage, adjacent joint arthritis, ligamentous injuries, and tendon pathology, which may also affect an ankle that is arthritic. Weight-bearing CT is a newer modality that allows us to evaluate the true bone positions in their loaded state to see the effects of cysts, malunions, and nonunions, or to maximize preoperative planning for osteotomies, fusions, or joint replacements.

Conservative Treatment

Nonoperative treatments for posttraumatic ankle arthritis or end-stage arthritis include nonsteroidal antiinflammatory drugs (NSAIDs), injections, use of cane, and orthotics. Injection options include corticosteroids, hyaluronic acid (HA), and platelet-rich plasma (PRP). Steroid injections can provide short-term relief, but repeat injections should be avoided due to catabolic risks to the soft tissue. Low quality studies have shown some improvement in pain and functional scores with hyaluronic acid injections for ankle osteoarthritis [20] although the Cochran review in 2015 states that it is unclear if there is benefit or harm for HA as a treatment for ankle osteoarthritis based on the current evidence [21]. There are a few studies that examined PRP injections for ankle osteoarthritis. Angthong et al. had a series of 5 patients with improvement in functional scores at mean follow-up of 16 months for ankle osteoarthritis [22]. Mei-Dan et al. compared PRP injection to HA in a randomized controlled trial of 30 patients with talar osteochondral lesions and reported improved pain and function in the PRP group [23]. Bone marrow aspirate concentrate (BMAC) injection is also being investigated as an option for ankle arthritis as an isolated treatment or in conjunction with surgical treatment [24]. A cane can unload the joint mechanically. A custom molded ankle-foot orthosis (AFO) that is molded to the calf muscle can unload the ankle. A rigid leather ankle lacer with a solid ankle cushion heel (SACH) and a rocker sole can limit ankle motion and help with pain relief.

Operative Treatment

The goal of surgical management of posttraumatic ankle arthritis is to improve pain, function, and restore alignment. The main surgical options include total ankle arthroplasty (TAA) and ankle arthrodesis (AA). In the last 20 years, we have seen other alternatives that include arthroscopic debridement, allograft transplantation, bipolar fresh total osteochondral allograft, periankle osteotomy, and distraction arthroplasty.

Posttraumatic ankle arthritis is the most common indication for ankle arthrodesis [25]. It is also an option as primary salvage following pilon fracture. It provides reliable pain relief with relatively low reoperation rates. The optimal position for fusion is neutral dorsiflexion, 5 degrees of hindfoot valgus, external rotation comparable to the contralateral side, and the anterior dome of the talus brought to anterior tibia [26]. Fusion can be achieved with open arthrodesis or arthroscopic arthrodesis, and internal fixation with screw or plate vs. external fixation can be used. Figure 12.1 shows preoperative and postoperative radiographs of a patient who underwent ankle arthrodesis for posttraumatic ankle arthritis with valgus deformity. The disadvantages of ankle arthrodesis include loss of ankle motion, decreased gait efficiency, and adjacent joint arthrosis [27]. Coester et al. reported 22-year follow-up in 23 patients who underwent ankle fusion for posttraumatic arthritis and found increased adjacent joint arthritis compared to the contralateral side [28]. Arthroscopic ankle arthrodesis is a good option for patients with limited angular deformities. O’Brien et al. compared arthroscopic to open ankle arthrodesis and found similar fusion rates with significantly less morbidity, shorter operative and tourniquet time, less blood loss, and shorter hospital stay [29]. Winson reported 71% excellent and good outcome in 116 patients who underwent arthroscopic ankle arthrodesis [30].

Total ankle arthroplasty was introduced in the 1970s, and early results were disappointing with a high rate of failure [31]. This was attributed to poor implant design, loosening, and instability [32]. Since then, the development of newer generation of total ankle implants with semiconstrained, cementless design with mobile and fixed bearing has become more popular [33]. The potential benefits of TAA is restoration of ankle kinematics and preventing adjacent joint arthritis. Figure 12.2 shows preoperative and postoperative radiographs of a patient who underwent a total ankle arthroplasty for posttraumatic ankle arthritis. Haddad et al. performed a

Fig. 12.1 (**a**) Shows the preoperative AP, oblique, and lateral radiographs of a patient with bimalleolar ankle fracture who developed posttraumatic ankle arthritis with collapse of the talus and valgus deformity. (**b**) Shows the postoperative AP, oblique, and lateral radiographs after treatment with removal of hardware and ankle arthrodesis

metaanalysis of the available outcome studies in 2007 that included 852 patients who underwent total ankle arthroplasty with second-generation implants and found 68% of excellent and good results [34]. The 5-year and 10-year implant survival rates were 78% and 77% with 7% revision rate [34]. A multicenter prospective non-randomized trial comparing Scandinavian Total Ankle Replacement (STAR) to ankle fusion in 593 patients showed that by 24 months, TAA had better function and equivalent pain relief as the fusion group [35]. Another multicenter prospective trail in Canada comparing 281 TAA and 107 AA in 5.5 year follow-up reported similar improvement in pain and function, but there was a higher major complication rate (19% vs. 7%) and higher revision rate (17% vs. 7%) in ankles treated with TAA vs.

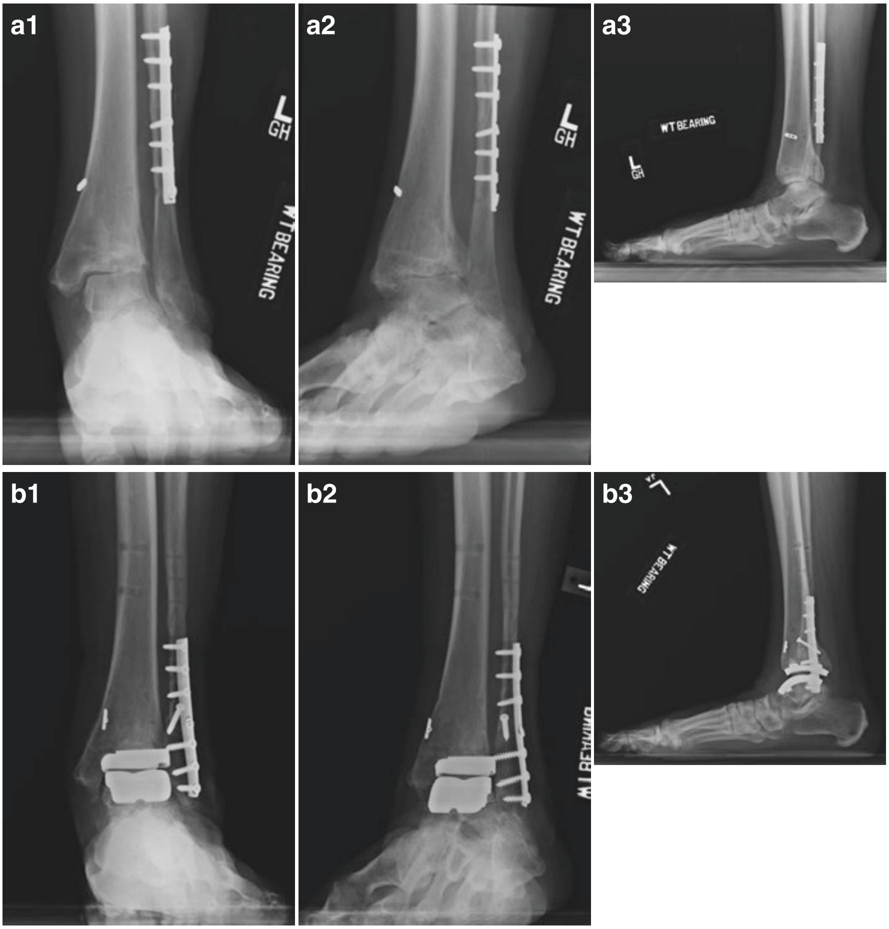

Fig. 12.2 (**a**) Shows the preoperative AP, oblique, and lateral radiographs of a patient with a lateral malleolar ankle fracture with syndesmosis injury status post ORIF and tightrope fixation who developed posttraumatic ankle arthritis. (**b**) Shows the postoperative AP, oblique, and lateral radiographs after treatment with transfibular total ankle arthroplasty

AA [36]. A new total ankle coinvented by the senior author was introduced in the USA 4.5 years ago. The design allows for conservation of bone stock, coronal plane orientation of the rails, porous tantalum surfaces, and highly crosslinked polyethylene. A fibular osteotomy is performed for full joint exposure with preservation of the deep deltoid. This osteotomy allows for correction of sagittal and coronal plane deformities. Of the 105 performed by the senior author, 80% had deformity correction of the tibia, talus, and fibula. Early results are promising with no fibular nonunion, malunion, or implant failure after 12 -months follow-up [37].

In patients with posttraumatic impingement syndrome, ankle arthroscopic debridement can be considered [38]. Arnold reported 81% good or excellent outcome with ankle arthroscopy with resection of hypertrophic synovium, fibrous bands, or tibial spurs after an ankle sprain. The poor outcomes were associated with severe chondral lesions found during arthroscopy. Rasmussen reported 62% pain free 2 years after arthroscopic debridement for impingement, and 27% had pain improvement [39].

In cases of patients with localized articular cartilage defects, allograft transplantation can be considered. It is performed with anatomically matched fresh allograft harvested within 24 hours of death and removal of bacteria, blood, and lipids. Hahn et al. reported significant improvement in pain and functional scores in 18 patients who underwent allograft transplantation for osteochondral lesions of the talar dome [40].

Severe posttraumatic ankle arthritis in young and active patients poses a reconstructive challenge and bipolar fresh total osteochondral allograft (BFTOA) may be an alternative to arthrodesis and total ankle replacement [41]. Figure 12.3 shows intraoperative pictures and postoperative radiographs of a patient who underwent bipolar fresh total osteochondral allograft. Giannini et al. reported improvement in functional scores at 40.9-months follow-up in 26 patients who underwent BFTOA for posttraumatic arthritis. Six out of the 26 patients had failure associated with malalignment of the tibial slope. Bugbee et al. reported 83% improved pain and function in 88 patients who underwent BFTOA at 5.3-year follow-up although 29% required another operation [42].

Supramalleolar osteotomy is an option for patients with varus or valgus ankle arthritis. The goal is to correct the ankle alignment for improved joint loading while preserving the ankle joint [43]. Medial opening wedge osteotomy is used to correct incongruent varus arthritis, and medial closing wedge osteotomy is used for valgus ankle arthritis [43]. Figure 12.4 shows preoperative and postoperative radiographs of a patient who underwent medial opening wedge osteotomy for ankle arthritis with varus deformity. Takakura et al. reported improved pain and function in 9 patients who underwent tibial osteotomy for varus ankle arthritis at 7-year follow-up [44]. Pagenstert et al. reported improved pain and function in 22 patients who underwent osteotomy for valgus ankle arthritis with 4.5-year follow-up [45]. Knupp et al. reported statistical significant improvement in functional scores in 92 patients who underwent osteotomy for varus or valgus ankle arthritis at 43-months follow-up [46].

In young and active patients with posttraumatic ankle osteoarthritis, ankle distraction is another option to preserve the joint. This technique involves external fixator with or without a hinge, and progressive distraction for 3 months while weight bearing. The theory is that by removing the mechanical stress, the cartilage can repair itself [47]. Figure 12.5 shows preoperative and postoperative radiographs of a patient who underwent ankle distraction arthroplasty. Tellisi et al. reported significant pain and functional improvement in 91% of patients who underwent ankle distraction in 25 patients with ankle arthritis at follow-up of 30 months [48]. Nguyen et al. reported intermediate-term follow-up of 36 patients who underwent ankle distraction for end-stage ankle arthritis, and 45% underwent subsequent ankle arthrodesis or total ankle arthroplasty due to pain [49].

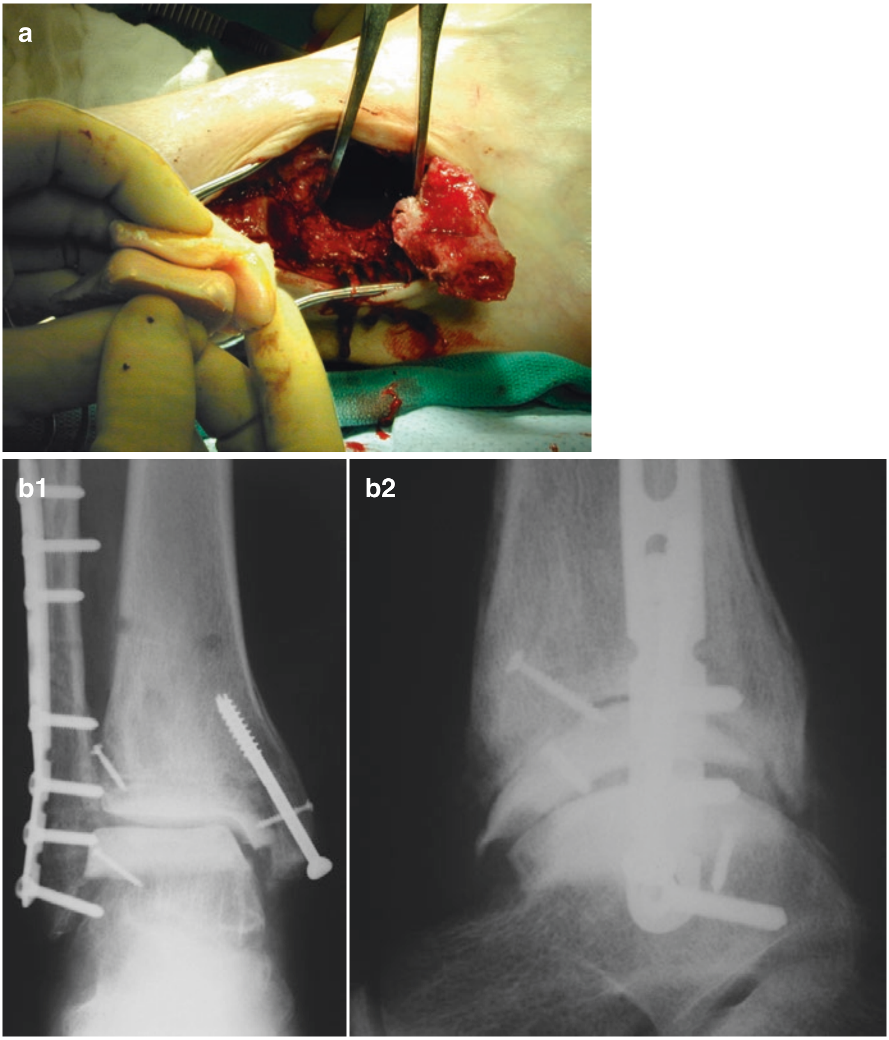

Fig. 12.3 (**a**) Shows an intraoperative photograph of the fresh allograft of the talar dome and tibial plafond prior to implantation. (**b**) Show AP and lateral postoperative radiographs of a patient with posttraumatic ankle osteoarthritis treated with bipolar fresh total osteochondral allograft. Note the small screw fixation in the tibia and talus

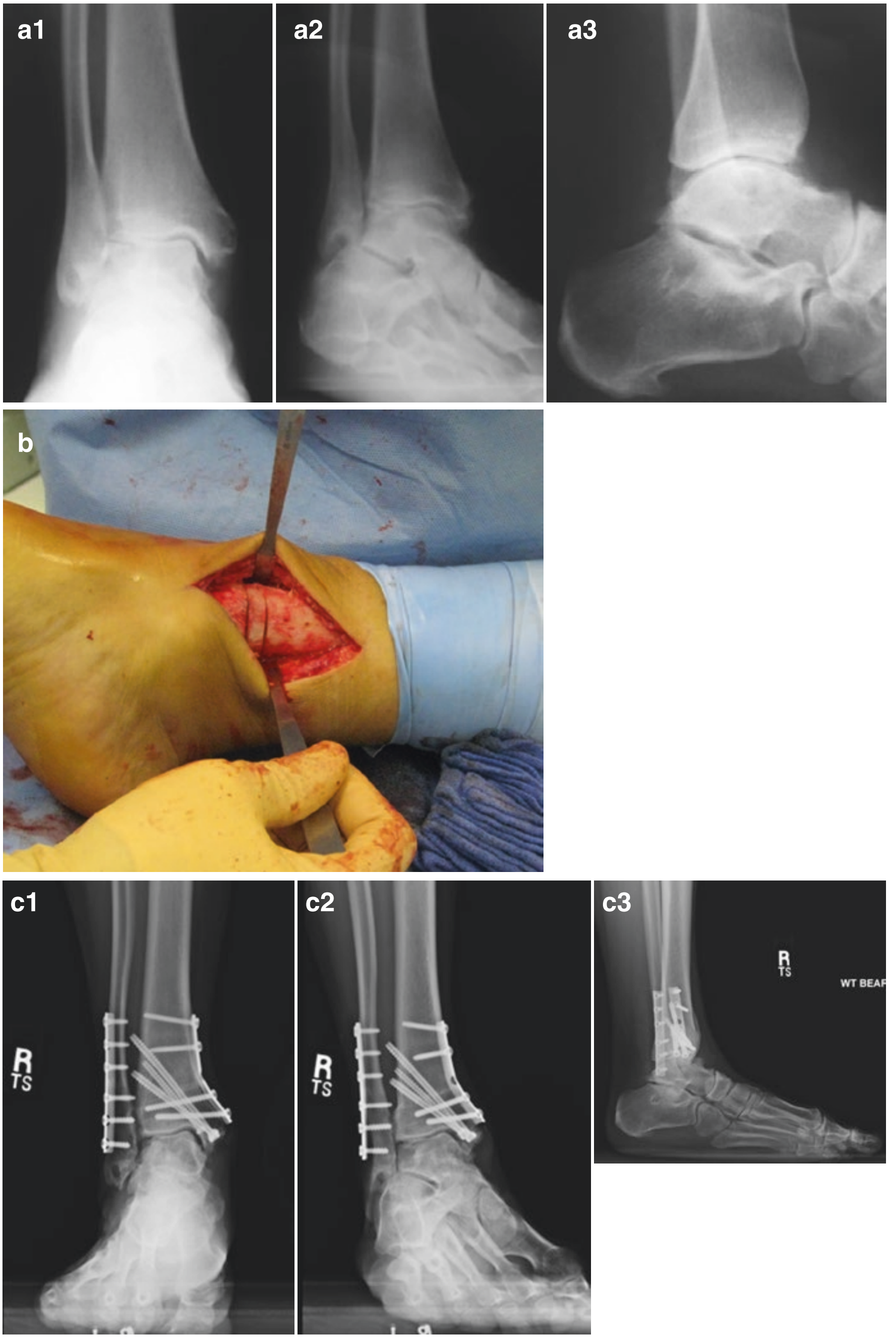

Fig. 12.4 (**a**) Show the preoperative AP, oblique, and lateral radiographs of a patient with varus deformity ankle arthritis treated with medial opening wedge osteotomy. (**b**) Shows the intraoperative image of the medial ankle with an allograft wedge. (**c**) Show the postoperative AP, oblique, and lateral radiographs demonstrating restored alignment

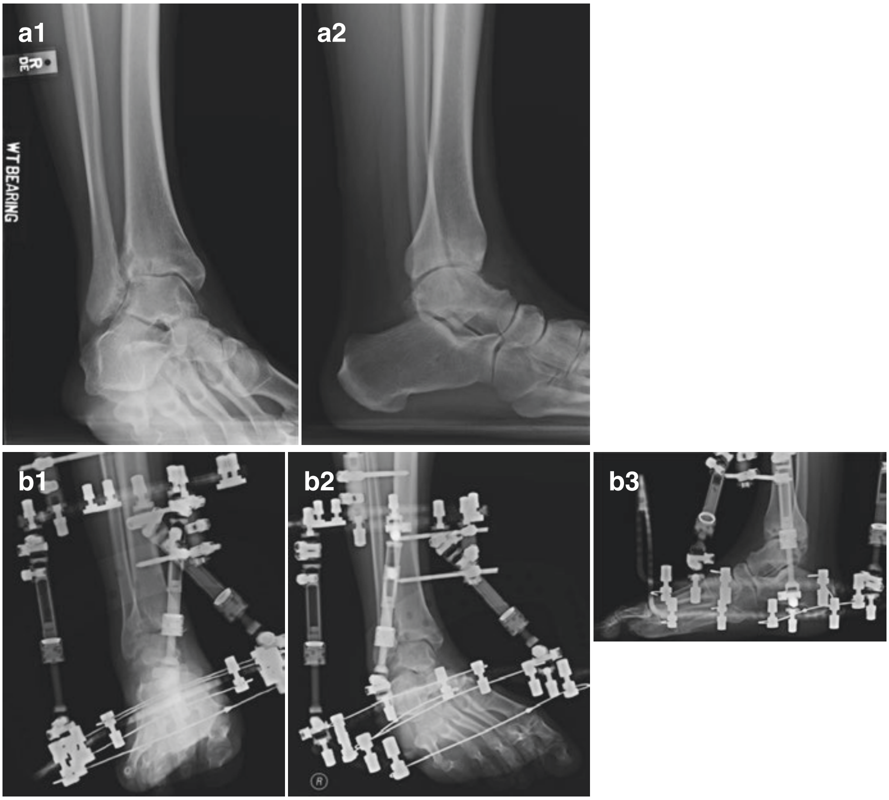

Fig. 12.5 (**a**) Shows the preoperative oblique and lateral radiographs of a young patient with post-traumatic ankle arthritis. (**b**) Shows the postoperative AP, oblique, and lateral radiographs after distraction arthroplasty with an external fixator that allows for ankle range of motion

Summary

Post-traumatic arthritis is the primary cause of arthritis in the ankle. It disproportionately affects younger individuals and athletes. Inflammatory events at the time of injury with release of cytokines can lead to irreversible damage to the cartilage. Nonoperative treatments for posttraumatic ankle arthritis include NSAIDs, corticosteroid injections, orthotics and bracing. Surgical treatment is based on the ankle alignment and severity of the arthritis. Primary surgical treatments for end stage ankle arthritis include total ankle arthroplasty and ankle arthrodesis. The literature supports both ankle arthrodesis and total ankle arthroplasty. Other treatment options include arthroscopic debridement, allograft transplantation, bipolar fresh total osteochondral allograft, supramalleolar osteotomy, and distraction arthroplasty. Patient specific factors such as medical comorbidities, malalignment, adjacent joint pathology, age and activity levels are important considerations when selecting the surgical treatment.

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Chapter 13
Post-traumatic Arthritis of the Foot

Ram K. Alluri and Eric W. Tan

Key Points

- The most common traumatic orthopaedic injuries of the hindfoot and midfoot are calcaneus fractures and tarsometatarsal (TMT) fracture-dislocations (Lisfranc injury), respectively.
- The hindfoot is structurally composed of the talus and calcaneus, and its functionality is primarily dependent on motion through the talonavicular and subtalar (talocalcaneal) joints.
- The Lisfranc complex is a major stabilizer of the midfoot and is composed of the five metatarsal base articulations with the cuboid and cuneiforms.
- The mainstay for surgical treatment involves selective arthrodesis with the goal of a creating a stable, functional, and painless plantigrade foot.

Introduction

Traumatic injuries of the foot are common after high-energy trauma, and second only to hip, thigh, and knee injuries [1]. Although these injuries of the foot are typically not life threatening, they can result in significant long-term functional disability, and in patients with multiple injuries, those with foot injuries have significantly worse outcomes than matched patients without foot injuries [2]. Much of the disability sustained after traumatic injuries to the foot is due to acute and chronic post-traumatic degenerative changes of the articular surfaces.

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S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7_13

The most common traumatic orthopaedic injuries of the hindfoot and midfoot are calcaneus fractures and tarsometatarsal (TMT) fracture-dislocations (Lisfranc injury), respectively. Calcaneus fractures account for approximately 2% of all fractures, and it is the most frequently fractured bone of the foot [3]. Fracture-dislocations of the TMT joint are relatively uncommon, only accounting for 0.2% of all fractures; [4] however, up to 20% of these TMT injuries are initially missed or misdiagnosed [5]. In both injuries, patients can develop symptomatic posttraumatic osteoarthritis due to intraarticular fracture fragments, altered biomechanics resulting in pathologic force distribution, and direct articular surface damage. Previous studies have demonstrated that chondrocyte injury and death can immediately occur due to forceful impaction during the traumatic event [6].

In this chapter, we will discuss the relevant anatomy, evaluation, and management of patients who sustain a calcaneus fracture or TMT fracture-dislocation and, subsequently, develop posttraumatic osteoarthritis of the hindfoot or midfoot.

Anatomy and Biomechanics

Anatomy

The hindfoot is structurally composed of the talus and calcaneus, and its functionality is primarily dependent on motion through the talonavicular and subtalar (talocalcaneal) joints. The majority of hindfoot motion occurs through the talonavicular joint with fusion of this joint resulting in 90% loss of subtalar motion. Conversely, subtalar fusion only results in 26% loss of talonavicular motion [7]. The subtalar joint is composed of two articulations. Anteriorly, the lip and sustentaculum of the calcaneus rotate about the talar head; posteriorly, the posterior facet of the calcaneus provides a surface for which the talus can glide upon. The spring ligament and the proximal articular surface of the navicular bone augment the calcaneus to form a complete socket stabilizing the talar head. Overall, the axis of the subtalar joint is oblique due to the more medial anterior talocalcaneal articulation relative to the posterior articulation.

The midfoot is composed of navicular, cuboid, and three cuneiform bones and articulates proximally with the hindfoot and distally with the forefoot. Functionally, the midfoot is often described in terms of medial, middle, and lateral columns. The rigid medial and middle columns are composed of articulations between the first metatarsal base and medial cuneiform, second metatarsal base and intermediate cuneiform, and third metatarsal base and lateral cuneiform. The mobile lateral column consists of the cuboid and fourth and fifth metatarsal bases. There are 5–10 degrees of motion at the first TMT joint and minimal motion occurs at the second and third TMT joints. The fourth and fifth TMT joints are most mobile, with 10–20 degrees of movement. The osseous stability of the midfoot is partly because of the wedge shape of the metatarsal bases and cuneiforms resulting in a transverse arch, or "Roman arch," of the foot in the coronal plane. A second osseous stabilizer is provided by recession of the second metatarsal base relative to the first and third tarsometatarsal joints.

The Lisfranc complex is a major stabilizer of the midfoot and is composed of the five metatarsal base articulations with the cuboid and cuneiforms. This complex is stabilized by a combination of ligamentous attachments and a unique bony configuration at the second metatarsal base. The dorsal ligaments are the weakest while the interosseous and plantar ligaments are the strongest [8]. The specific Lisfranc ligament stabilizes 1–2 intermetatarsal bases, attaching the second metatarsal base to the medial cuneiform. While intermetatarsal ligaments are present between the second, third, fourth, and fifth metatarsal bases, there is no intermetatarsal ligament stabilizing the 1–2 metatarsal bases directly. Therefore, the integrity of the Lisfranc ligament is critical for stability.

Altered Biomechanics

Fractures of the calcaneus can result in significant articular damage and progressive hindfoot deformity resulting in a heel that is wide, flattened, and in varus (Figs. 13.1 and 13.2). Widening of the hindfoot may cause significant difficulty with shoe wear. The varus deformity can cause lateral deviation of the peroneal tendons and sural nerve compression [9]; severe varus deformity can cause symptomatic subfibular impingement between the lateral wall of the calcaneus and distal fibula [9]. When

Fig. 13.1 Axial heel view and lateral radiographs of a simple, intraarticular calcaneal fracture

Fig. 13.2 Axial heel view and lateral radiographs of a complex, intraarticular calceanal fracture with significant intraarticular comminution and joint depression

the hindfoot assumes a pathological varus alignment, the transverse tarsal joint remains locked, resulting in subsequent degeneration of the adjacent midfoot joints due to persistently increased loads during gait [9]. Hindfoot varus deformity can also cause lateral column overloading of the midfoot. In addition to varus deformity, loss of hindfoot height from depression of the posterior calcaneal facet can also occur after calcaneal fractures [9]. This causes the talus to adopt a more dorsiflexed position, which may result in anterior impingement of the talus on the anterior tibial plafond [9]. Additionally, the lever arm of the Achilles tendon is reduced, which can significantly alter normal gait patterns [9].

Traumatic injuries to the Lisfranc complex occur during torsion of the forefoot and axial load transmission to the midfoot (Figs. 13.3 and 13.4). These injuries result in direct articular damage and altered midfoot biomechanics due to instability and resultant collapse of the longitudinal arch. The normal intact midfoot arch functions as a lever, efficiently transmitting force from the forefoot to hindfoot, and loss of this arch results in decreased mechanical efficiency [10]. This leads to abnormal loading of the midfoot and adjacent joints, resulting in arthritic degeneration. Commonly, patients develop a valgus deformity of the hindfoot, midfoot flattening from the loss of the longitudinal arch, and forefoot abduction and dorsiflexion because of pathologic changes in the peroneus brevis and posterior tibialis tendons, respectively.

Fig. 13.3 Anteroposterior (AP), oblique, and lateral radiographs of a subtle Lisfranc injury with mild diastasis between the medial cuneiform and the base of the second metatarsal that could be missed during initial presentation

Fig. 13.4 Anteroposterior (AP), oblique, and lateral radiographs of a severe Lisfranc injury with homolateral shift of the first through fifth tarsometatarsal joints

Natural History of Initial Hindfoot and Midfoot Fracture Healing

During the acute injury, a calcaneus fracture can be treated operatively or nonoperatively; however, no definite consensus exists with regard to ideal treatment. Current relative indications for operative management include large extraarticular fractures, fractures with greater than 2 mm of intraarticular displacement, flattening of Bohler's angle and the angle of Gissane, varus malalignment of the tuberosity, impending skin necrosis from displaced tongue-type fractures, and open fractures. Relative nonoperative indications include anterior process fractures involving <25% of the calcaneocuboid joint, fractures with preserved calcaneal height, nondisplaced fractures, fractures with less than 2 mm of intraarticular displacement, or patients with comorbidities (smoking, diabetes, vascular disease) placing them at increased risk for postoperative complications [11].

Prior studies have stressed the importance of achieving an anatomic reduction to prevent accelerated wear of the subtalar joint. Minimal displacement of 1–2 mm has been shown to alter contact pressures of the subtalar joint and posterior facet, resulting in significant gait disturbance [12, 13]. Whether achieved through open or closed reduction, anatomic reduction of calcaneal fractures attempts to recreate a congruent subtalar joint, reduce the lateral wall, and take the hindfoot out of varus while restoring calcaneal height. Therefore, most surgeons advocate initial operative management to achieve an anatomic reduction of the joint surface to potentially decrease the incidence of subtalar osteoarthritis requiring secondary arthrodesis [14, 15].

Several prior studies have attempted to delineate the ideal management of displaced intraarticular calcaneal fractures. In a study by Agren et al., surgical treatment was associated with higher complications and similar functional outcomes at 1 year compared to nonoperative management [16]. Buckley et al. also found little difference in SF-36 or VAS outcome scores between operatively and nonoperatively treated calcaneus fractures [15]. However, the authors did note higher rates of eventual arthrodesis in patients who received initial nonoperative management [15]. Csizy et al. noted similar findings with a six times higher subtalar arthrodesis rate in patients receiving initial nonoperative management [14].

Regardless of initial operative or nonoperative management, a high number of patients who sustain calcaneal fractures with significant intraarticular involvement will develop posttraumatic osteoarthritis [17]. The initial injury results in the displacement of intraarticular fracture fragments and irreversible cartilage damage. In a study by Radnay et al., 69 patients who sustained a calcaneal fracture requiring eventual arthrodesis were reviewed [18]. Thirty-four (49%) underwent initial operative management, and 35 (51%) were treated initially nonoperatively [18]. Worse functional outcomes after subtalar arthrodesis were noted in patients who were initially treated with nonoperative management [18]. Patients with initial nonoperative management also had greater postoperative wound complications, potentially due to greater restoration of calcaneal height resulting in postoperative tension along the surgical wound [18].

The initial management of Lisfranc injuries also remains without consensus, partly because the term "Lisfranc injury" reflects a wide and poorly defined injury spectrum. Initial management includes nonoperative interventions versus open reduction and internal fixation (ORIF) or primary partial arthrodesis of the midfoot. Nonoperative management is generally reserved for patients who are minimally ambulatory, have an insensate foot, or inflammatory osteoarthritis [19]. In patients without these preexisting comorbidities, nonoperative management is generally only recommended in patients with a stable injury (no diastasis of the Lisfranc complex).

Any measurable incongruity greater than 2 mm at the Lisfranc joint is generally an indication for surgical treatment, ideally within the first two weeks after injury to optimize outcomes [19]. The most accurate predictor of postoperative outcome is achieving a stable anatomic reduction after which good to excellent postoperative outcomes can be expected in 85% of patients whereas nonanatomic alignment results in similar outcomes in only 17% of patients [20]. Even after adequate reduction, the incidence of posttraumatic osteoarthritis can be as high as 25–72% [21, 22]. However, up to 100% of patients with an inadequate initial reduction will develop posttraumatic osteoarthritis [21], and initial radiographic findings are generally not predictive of which patients will develop this complication [23]. Some authors have stated that developing osteoarthritis after a Lisfranc injury is almost inevitable given the damage to the articular surface at the time of initial injury [24]. Given these findings, some surgeons recommend primary partial fusion in Lisfranc injuries at high risk for developing posttraumatic osteoarthritis such as injuries with ligamentous disruption and multidirectional instability, significant comminution, or crush injuries [25]. Although partial midfoot arthrodesis may limit or eliminate the eventual development of posttraumatic midfoot osteoarthritis, the stiffness and limited function of the foot following the arthrodesis may not be well tolerated in young, active patients.

Patient Evaluation

History

The preoperative examination of all patients with posttraumatic osteoarthritis secondary to a hindfoot or midfoot injury should begin with a thorough history. The history should focus on the initial mechanism of injury and soft tissue damage, previous nonoperative or operative treatment received, degree of current disability and pain, and a discussion of current expectations in terms of functional outcome. An assessment of current medical comorbidities, work status, and tobacco use can allow for perioperative risk stratification and assessment of nonunion risk.

Physical Exam

The physical exam should consist of a gait assessment, range of motion measurement, and careful inspection of ankle and foot alignment. Alignment should be assessed with the patient standing as this best allows for examination of hindfoot varus or valgus, medial arch height, and forefoot abduction. Patients should also be asked to walk to assess for dynamic flatfoot deformity or subfibular impingement. Abnormal alignment should be assessed for passive correctability, and in a patient with unilateral injury, the contralateral, uninjured side can serve as a reliable control. In cases of severe deformity, the quality of the soft tissue and presence of ulcers or impending skin breakdown should be assessed. Previous surgical scars should be examined as they can dictate choice of surgical exposure. The dorsalis pedis and posterior tibial pulses should be assessed; nonpalpable pulses may require a preoperative vascular consult. Lastly, the strength and sensation of the foot should also be formally assessed and documented.

In patients with posttraumatic hindfoot deformity and osteoarthritis, the hindfoot is often in varus and collapsed, and therefore evaluation for contractures of the gastrocnemius-soleus complex and anterior ankle impingement is important. Additionally, patients with posttraumatic hindfoot osteoarthritis may have a widened calcaneus that can cause skin breakdown over the lateral malleolus from contact friction.

In patients with posttraumatic midfoot deformity and osteoarthritis, excessive pronation and midfoot collapse may be noted secondary to loss of the longitudinal arch and acquired forefoot abduction. These patients may have pain with palpation over the midfoot; however, the degree of arthrosis visualized on radiographs may not correlate with symptoms found on physical examination. In most cases, patients endorse greatest pain at the second TMT joint as this is the least mobile joint of the midfoot and undergoes the greatest posttraumatic arthritic change. To a lesser extent, they may endorse pain at the first and third TMT joints. Patients with arthrosis of the lateral column may not endorse significant pain because of the inherent mobility of this column. Stress testing of individual metatarsocuneiform joints (the “piano key” test) may also help elicit pain across the affected midfoot TMT joints as it places compression along the medial and lateral midfoot [26]. A positive test will produce localized pain at the involved tarsometatarsal joint. Additionally, the examiner may be able to aggravate posttraumatic midfoot osteoarthritis symptoms by having the patient perform a single heel rise or stair ascent as these activities require significant load transmission across the midfoot. Lastly, dorsal osteophytes may cause difficulty with shoe wear, neuritis, or tendonitis.

Imaging

Weight-bearing anteroposterior, lateral, and oblique plain radiographs of the foot are necessary to diagnose and characterize the degree of arthrosis in the hindfoot or midfoot based on the presence of joint space narrowing, subchondral sclerosis, and osteophyte formation. The lateral view is particularly useful to assess talar declination, hindfoot collapse, and the presence of anterior impingement of the talar neck on the tibial plafond. Measurement of Bohler's angle or the angle of Gissane can help quantify the loss of calcaneal height due to posterior facet collapse (Fig. 13.5). Additionally on the lateral view, Meary's angle can be calculated in patients with loss of the medial longitudinal arch and subsequent pes planus deformity (Fig. 13.5). An axial heel view, or Harris view, can be useful to assess hindfoot alignment and heel widening. Some surgeons may elect to obtain plain radiographs of the uninjured foot for comparative purposes.

The role of computed tomography (CT) in evaluating posttraumatic arthrosis of the hindfoot and midfoot is unclear. Many surgeons recommend routinely obtaining CT imaging as it can assist in preoperative planning, particularly in cases of complex deformity. CT imaging allows for more accurate characterization of the degree

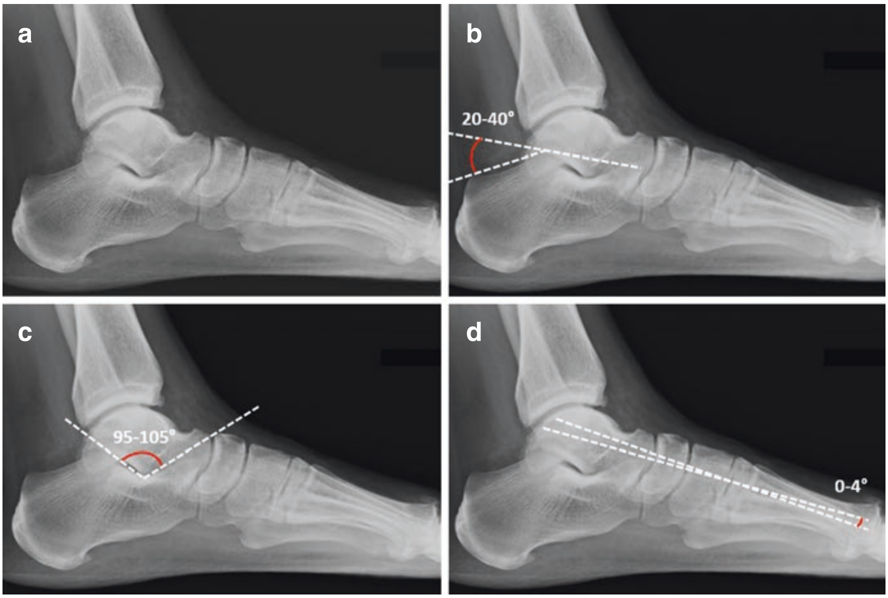

Fig. 13.5 (**a**) Normal lateral radiograph of the foot. (**b**) Bohler's angle. (**c**) Angle of Gissane. (**d**) Meary's angle. Normal values for the respective angles are listed within the image. The curved red line demonstrates where the angle should be measured

and location of hindfoot and midfoot arthrosis. Specifically, in hindfoot posttraumatic arthrosis, CT may allow for the determination of whether there is subfibular impingement of the calcaneus and distal tip of the fibula. With regards to midfoot posttraumatic arthrosis, CT images in three planes can allow for determining which specific midfoot joint is undergoing posttraumatic degeneration, potentially allowing for limited fusion, thus preserving greater function.

Magnetic resonance imaging (MRI) is not routinely utilized. In rare cases, a technetium Tc- 99 m bone scan can be ordered in patients with normal plain radiographs to identify early-onset arthritic changes in patients with persistent posttraumatic hindfoot or midfoot pain.

Nonoperative Management

The central treatment modalities of nonoperative management for posttraumatic osteoarthritis of the hindfoot and midfoot center on physical therapy, nonsteroidal antiinflammatory medications (NSAIDs), injections, and bracing. Activity modification, physical therapy, and NSAIDs are generally firstline treatments in this patient population. Selective injection of corticosteroids or hyaluronic acid in the hindfoot or midfoot is also an option, but scientific evidence proving their efficacy is lacking.

Braces and orthotics provide pain relief and increased function for patients with hindfoot and midfoot osteoarthritis by decreasing force transmission and motion across the arthritic joint. The selection of the appropriate brace or orthotic depends on the degree of osteoarthritis present as well as the flexible or rigid nature of the deformity. In addition, the provider should be cognizant about the materials used and pressure applied by the brace or orthotic, as this may result in skin breakdown or ulceration. In early stages of hindfoot or midfoot osteoarthritis with flexible or minimal deformity, a semirigid ankle brace or custom orthotic may provide enough stability to support and realign the foot and ankle. As the severity of the osteoarthritis and deformity increases, a more rigid brace, such as a double-upright brace or custom Arizona brace, or rigid orthotic may be necessary to reduce motion at the affected hindfoot or midfoot joints, respectively. However, many patients find these braces cumbersome and difficult to use. Shoe wear modification, particularly rocker-bottom shoes or customized shoes, may also be effective nonoperative treatment options.

Operative Management

Patients that have failed nonoperative management of posttraumatic hindfoot and midfoot osteoarthritis with continued debilitating symptoms may be candidates for surgical intervention. Patient factors such as age, medical comorbidities, smoking history, profession, and workers' compensation status should be considered as these can significantly affect postoperative outcomes. The mainstay for surgical treatment involves selective arthrodesis with the goal of a creating a stable, functional, and painless plantigrade foot.

Hindfoot

Fractures of the calcaneus that develop posttraumatic osteoarthritis can be surgically treated with in situ subtalar arthrodesis or distraction bone-block arthrodesis with or without additional corrective osteotomies, lateral wall decompression, or soft tissue procedures.

In situ arthrodesis can provide significant pain relief with satisfactory functional outcomes (Fig. 13.6). It is indicated for patients with minimal deformity, significant subtalar osteoarthritis, and gross preservation of calcaneal height such that there is no evidence of anterior talar impingement on the tibial plafond. Patient selection is key for this in situ procedure as patients with deformity that is not addressed will inevitably have poorer long-term outcomes [27]. The choice of surgical approach for in situ arthrodesis must be given careful consideration. If previous hardware is present, but asymptomatic, it can be left in place [9, 28]. If the hardware is symptomatic, some surgeons elect to use the previous surgical incision, which is commonly an extensile lateral approach or, more recently, a sinus tarsi approach [9, 28]. After adequate exposure of the subtalar joint has been achieved, cartilage and nonviable bone are completely removed from the subtalar joint with care taken to

Fig. 13.6 Lateral radiograph of an intraarticular calcaneus fracture that was initially treated with open reduction and internal fixation (upper image). The patient eventually developed significant subtalar posttraumatic osteoarthritis. Postoperative lateral radiograph after removal of hardware and in situ subtalar arthrodesis (lower image). (Images courtesy of Dr. David E. Oji, MD)

preserve the normal bone contour and subchondral bone. The exposed subchondral bone is then meticulously prepared and perforated to improve blood flow. The subtalar joint is then aligned in approximately 0–5 degrees of valgus and fixed using partially threaded 6.5 mm screws. It is important to obtain correct hindfoot positioning prior to arthrodesis to maximize functional outcomes. Residual bony deficits can be filled with autologous bone graft, bone allograft, synthetic bone, or cancellous chips.

Previous studies have demonstrated union rates ranging from 84% to 98% after in situ arthrodesis on average 12 weeks after surgery [29, 30] and improvement in functional outcomes after arthrodesis: [18, 31] the AOFAS hindfoot score can be as high as 89 at final follow-up [32], and 93% of patients have good to fair outcomes using the Angus and Cowell rating system [31]. Overall patient satisfaction can range from 70% to 90% [33, 34]. The most common complication after this procedure is wound infection, which has recently been shown to be as high as 18%, especially in patients with an original open fracture or infection after the index operation [30]. Other complications include neuromas and chronic regional pain syndrome. Patients at higher risk for poorer functional outcomes include those initially treated nonoperatively, smokers, diabetics, and patients of advanced age [18, 35, 36].

In patients with loss of hindfoot height and symptomatic anterior tibial impingement, distraction bone-block subtalar arthrodesis is indicated (Fig. 13.7). An in situ arthrodesis in these patients, even with lateral wall decompression, will not optimize posttraumatic hindfoot function. The added distraction with a structural bone graft and arthrodesis will reestablish the calcaneal height as well as the inclination of the talus and normalize the gastrocnemius-soleus lever arm. Most commonly, the subtalar joint is approached with a posterior or posterolateral incision for this procedure. Alternatively, a sinus tarsi incision may also be utilized. However, an extensile lateral approach, commonly used for initial operative fixation of calcaneal fractures, should be avoided due to concerns about wound healing after distraction, particularly along the horizontal limb. After initial dissection through the soft tissues, a lateral wall exostectomy may be performed; the bone can be used as bone graft. The subtalar joint is then distracted using a large distractor or laminar spreader to correct the calcaneal height and varus malalignment. The joint surfaces are then prepared in a similar fashion to in situ subtalar arthrodesis. Next, the structural bone graft is inserted into the distraction gap and the hindfoot is placed into 0–5 degrees of valgus. Once aligned, the fusion may be secured using partially threaded 6.5 mm screws placed from the posteroinferior aspect of the calcaneus into the talar dome.

Tricortical iliac crest bone autograft is the main choice for structural grafting. However, structural allografts such as the femoral neck allograft and tricortical iliac crest allograft are alternative options. Initial reports comparing structural allograft to autograft demonstrated significantly lower union rates with allograft [37]; however, more recent studies report 92% union rates with allograft and favorable outcomes [38]. Augmentation of structural graft with synthetic bone graft substitutes or cancellous chips can be utilized at the surgeon's discretion.

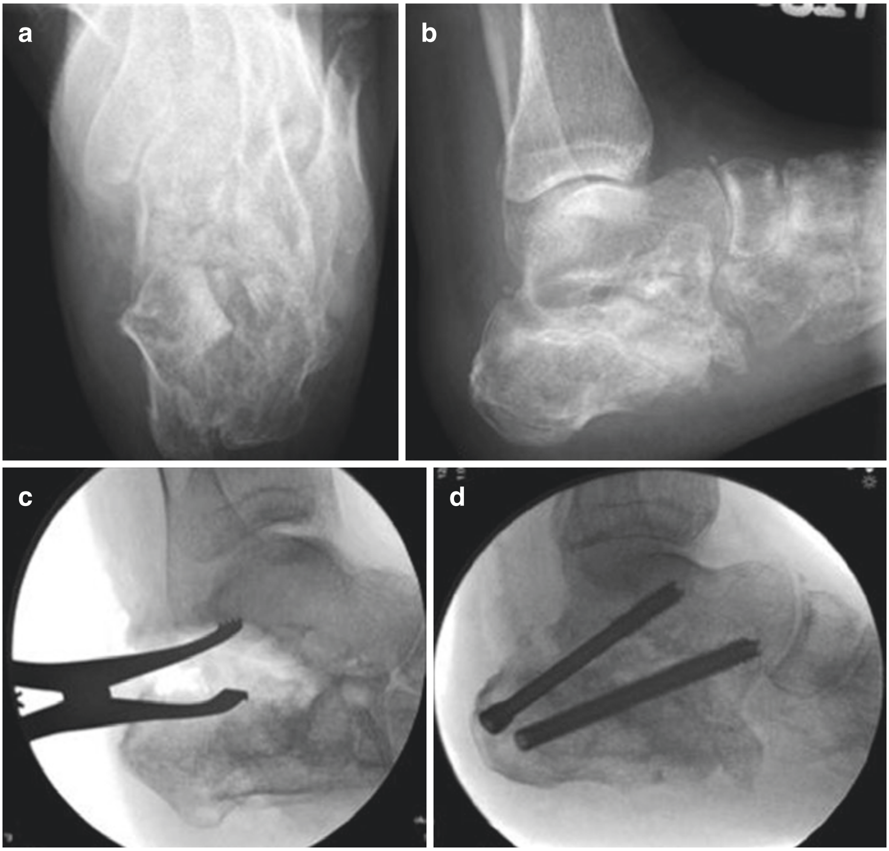

Fig. 13.7 (**a**, **b**) Axial heel view and lateral radiographs of an intraarticular calcaneus fracture initially treated nonoperatively. The patient developed significant subtalar posttraumatic osteoarthritis with varus hindfoot alignment and anterior talar impingement due to loss of calcaneal height. (**c**). Intraoperative fluoroscopic image demonstrating distraction of the subtalar joint using a laminar spreader (**d**). Intraoperative fluoroscopic image after distraction bone-block arthrodesis of the subtalar joint

Outcomes after distraction bone-block subtalar arthrodesis are generally favorable. Although the procedure is technically more challenging, as two osseous surfaces need to be united, union rates are similar to that for in situ subtalar arthrodesis, ranging from 87% to 95% [35, 37]. In a prospective study by Rammelt et al., AOFAS hindfoot scores increased from 23.5 to 73.2 at 33 months after distraction arthrodesis [39]. Other studies have demonstrated similar results, all with AOFAS hindfoot scores ranging from 70 to 76 at final follow-up [40–42], and over 90% of patients report satisfaction with the procedure [37, 39]. Although distraction bone-block subtalar arthrodesis is generally a successful procedure, complications can occur in up to 13% of patients [39]. The most common complications include infection, plantar exostosis, and nerve injury. Patients at risk for complications and poorer postoperative outcomes include diabetics, smokers, and workers' compensation patients [35, 41].

Occasionally with both subtalar arthrodesis techniques, additional soft tissue procedures may be needed. In the setting of peroneal subluxation or tendonitis, the peroneal tendons may need to be debrided, repaired, or reconstructed. Furthermore, percutaneous lengthening of the Achilles tendon or a Strayer gastrocnemius recession may be indicated in the setting of equinus deformity.

Importantly, fusion of the hindfoot for symptomatic posttraumatic osteoarthritis can result in increased stress across adjacent joints. Subtalar joint arthrodesis can result in greater force transmission across the adjacent transverse tarsal joint and tibiotalar joint. However, the clinical significance of adjacent joint degenerative changes remains unclear. Previous studies have demonstrated adjacent joint degenerative changes in the tibiotalar and transverse tarsal joints in 10–40% of patients [32, 33, 36, 37]. Whether these adjacent degenerative changes were present prior to subtalar fusion or were advanced due to fusion is unclear [32].

Midfoot

Fracture-dislocations of the TMT joint that develop posttraumatic osteoarthritis are commonly treated with arthrodesis of the medial three TMT joints (Fig. 13.8) [10, 28]. Similar to posttraumatic hindfoot osteoarthritis, the main indication for midfoot arthrodesis is patients who continue to have symptomatic pain refractory to nonoperative management.

The midfoot can be accessed through multiple incisions. In most cases, the incision used for arthrodesis is similar to that used for primary open reduction of acute Lisfranc injuries. A longitudinal incision made along the dorsal first intermetatarsal space allows access to the first and second tarsometatarsal joints. A second incision can be made over the dorsal fourth metatarsal with care to maintain an adequate skin bridge to access the third, fourth, and fifth TMT joints, if necessary. Alternatively, fusion of the first, second, and third TMT joints can be performed through a medial incision in conjunction with a central dorsal incision just lateral to the second metatarsal. Regardless of the approach, care should be taken to avoid and protect the dorsal pedis artery, first dorsal metatarsal artery, and the superficial and deep peroneal nerves.

The decision of which midfoot joints to fuse is critical and selective fusion is advocated to avoid making the midfoot overly rigid. Most commonly, the first, second, and third TMT joints are included in the arthrodesis. Additional fusion or interpositional tendon arthroplasty of the fourth and fifth TMT joints is rarely indicated but may be needed in cases of significant midfoot osteoarthritis. The selected joints of the midfoot arthrodesis construct should be denuded of residual cartilage and fibrous tissue. The subchondral bone is then debrided and perforated to improve blood flow to the fusion site. After adequate preparation of the bony surfaces, the mechanical alignment of the midfoot must be restored. A Hintermann distractor or

Fig. 13.8 (**a**, **b**) Anteroposterior (AP) and lateral radiographs of a patient with a prior Lisfranc injury who developed significant midfoot posttraumatic osteoarthritis. (**c**, **d**) Postoperative radiographs after arthrodesis of the first, second, and third tarsometatarsal joints of the midfoot. (Images courtesy of Dr. David E. Oji, MD)

lamina spreader can aid in restoring alignment and, occasionally, in more severe deformities, a wedge resection across the midfoot may be necessary [28].

In addition, soft tissue procedures may be needed to fully correct the deformity. In the presence of severe abduction deformity, lengthening or complete release of the peroneus brevis tendon may be needed. The tendon can also be transferred to the peroneus longus to help stabilize the medial column of the midfoot. Furthermore, in the presence of equinus deformity, percutaneous lengthening of the Achilles tendon or a Strayer gastrocnemius recession may be necessary.

After reestablishing alignment of the midfoot, residual bony deficits should be filled with autologous bone graft, bone allograft, synthetic bone graft substitutes, or cancellous chips. To stabilize the arthrodesis, multiple techniques are available including use of Kirschner wires, staples, compression screws as well as dorsal, medial, and plantar plates. There is no clear evidence indicating which construct leads to the best clinical outcomes [10]. However, Marks et al. demonstrated that midfoot fusions fixed with a plantarly applied plate result in superior biomechanical stability compared to midfoot fusion constructs with screw fixation [43]. In most cases, adequate stability can be achieved with partially threaded cancellous screws or cortical lag screws placed across each joint of the arthrodesis construct. In cases of severe deformity, the addition of compression plates or plantar plate fixation will add additional stability and should be considered.

The results of midfoot fusion for posttraumatic osteoarthritis after a TMT joint fracture-dislocation are generally favorable. Union is achieved in greater than 90% of patients with some studies demonstrating 98% union rates [44, 45]. Sangeorzan et al. reported good to excellent results in 11 of 16 patients (69%), and 15 of 16 (94%) were satisfied with the procedure [46]. Mann et al. reported 93% patient satisfaction following selective arthrodesis [44], and Johnson and Johnson reported 84% patient satisfaction [47]. AOFAS-midfoot scores can improve by up to 34 points with final scores ranging from 71 to 78 [48, 49]. Several studies have shown that the quality of the initial reduction during the acute TMT fracture-dislocation correlates with better outcomes after secondary midfoot arthrodesis [20, 46] while workplace injuries and delay to treatment can negatively affect outcomes [46]. The most common complications after midfoot fusion include superficial infections, neuritis, and neuromas [44, 47, 48]. Nerve injuries are common in midfoot fusion due to the anatomic location of the cutaneous nerves, particularly the deep peroneal nerve, and the soft tissue retraction needed for adequate exposure and preparation of the joint surfaces.

Similar to subtalar fusion of the hindfoot, concerns exist for adjacent joint degenerative changes after select midfoot fusion; however, no clinical studies exist that have objectively evaluated this potential complication.

Conclusions

Calcaneus fractures and TMT fracture-dislocations of the hindfoot and midfoot, respectively, can result in significant long-term morbidity primarily due to the development of posttraumatic osteoarthritis secondary to acute articular damage at the time of initial injury and chronic malalignment and abnormal force distribution across the foot resulting in progressive degeneration. Restoration of the articular surface and a stable reduction during initial treatment can decrease the risk of developing posttraumatic osteoarthritis, but, regardless of initial treatment, a certain subset will inevitably develop posttraumatic osteoarthritis. In symptomatic patients with posttraumatic osteoarthritis refractory to nonoperative management, select fusion of the subtalar joint with or without bone block distraction or medial and middle columns of the midfoot can result in good to excellent postoperative functional outcomes and high rates of patient satisfaction.

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Index

A
Acetabular fractures, 31
antero-lateral approach, 124, 131
bimodal distribution, 112
cement-less acetabular components, 128, 129
complications, 131
Harris hip score, 124, 128, 129
heterotopic ossification, 130
hypotensive anesthesia, 114
implant loosening, 130
implant selection, 114
incidence, 112
internal fixation, 112, 114
intra-operative fluoroscopy, 114
Kaplan–Meier survivorship, 131
open reduction, 112
open reduction internal fixation, 115, 130
postero-lateral approach, 114, 124, 130, 131
post-operative care, 115
revision surgery, 128
surgical planning, 113, 114
total hip arthroplasty, 112, 115, 128–132
Affordable Care Act (ACA), 38
Ankle osteoarthritis
allograft transplantation, 191
anatomy, 186
ankle arthrodesis, 188
bipolar fresh total osteochondral allograft, 191
conservative treatment, 187, 188
epidemiology, 186, 187
fibular osteotomy, 190
operative treatment, 188–191
patient evaluation, 187
prevalence, 185
Scadanavian Total Ankle Replacement, 189
supramalleolar osteotomy, 191
total ankle arthroplasty, 188
Anterior cruciate ligament (ACL), 27
Arthroplasty
hemiarthroplasty, 50, 51
humeral resurfacing, 51
reverse shoulder arthroplasty, 51, 52
total shoulder arthroplasty, 49, 50
Articular cartilage
functional unit, 5
homeostasis, 10
osteoarthritic, 7–9

B
Bipolar fresh total osteochondral allograft (BFTOA), 191
Bone marrow aspirate concentrate (BMAC) injection, 188
Bone marrow edema, 21, 22
Bone remodeling, 5

C
Calcaneus fracture, 200, 201
Capsulorrhaphy arthropathy, 47
Carpal instability adaptive (CIA), 78
Carpal instability dissociative (CID), 75
Carpometacarpal (CMC) arthritis, 105, 106
Carpus and intercarpal joints, 74, 76
Cartilage degeneration, 7
Cartilage homeostasis, 5

S. C. Thakkar, E. A. Hasenboehler (eds.), *Post-Traumatic Arthritis*,
https://doi.org/10.1007/978-3-030-50413-7

Conventional radiography (CR)
 arthroscopy confirmed grade II femoro-tibial chondromalacia, 18
 disadvantages, 18
 5-point K-L scoring system, 16
 joint space narrowing, 16, 19
 K-L method, 18
 malleolar fracture, 18
 Takakura method, 18
 talar tilt angle, 18
 Van Dick method, 18

D
Darrach procedure, 91
Distal femur fractures
 epidemiology, 153, 154
 intra-articular correction of deformity, 162, 164
 natural history, 154, 155
 nonoperative management of post-traumatic arthritis, 155
 operative management of post-traumatic arthritis, 155, 156
 patient evaluation, 155
 primary arthroplasty, 156, 157
 staged osteotomy, 158, 159
 total knee arthroplasty, 158
Distal humerus hemiarthroplasty, 67
Distal interphalangeal (DIP) arthritis
 arthroplasty, 100
 bony mallet finger injuries, 98
 carpometacarpal arthritis, 105, 106
 complications, 98
 compression screw, 98
 conservative treatment, 98
 flexor digitorum profundus avulsion injuries, 98
 Herbert compression screws, 99
 K-wire, 98
 metacarpophalangeal joint arthritis, 103, 104
 proximal interphalangeal joint injuries, 100–103
 steroid injections, 98
Distal radioulnar joint (DRUJ), 76

E
Elbow arthrodesis, 69
Elbow fracture
 bimodal age distribution, 60
 classification, 60
 distal humerus hemiarthroplasty, 67
 elbow arthrodesis, 69
 interpositional arthroplasty, 66, 67
 intra-articular distal humerus fractures, 60
 nonsurgical treatment, 62
 osteocapsular debridement arthroplasty, 63–66
 post-traumatic elbow stiffness, 61
 radiocapitellar arthroplasty, 67
 surgical planning, 61, 62
 surgical treatment, 62
 total elbow arthroplasty, 68, 69
Extensor pollicis longus (EPL), 88

F
Finite element simulation study, 5
Foot injuries
 anatomy, 200, 201
 arthritic degeneration, 202
 calcaneus fracture, 200, 201
 hondrocyte injury, 200
 hindfoot and midfoot fracture healing, 204, 205
 hindfoot varus deformity, 202
 imaging, 207, 208
 long-term functional disability, 199
 nonoperative management, 208
 operative management
  hindfoot, 209, 210, 212
  midfoot, 212–214
 physical examination, 206
 preoperative examination, 205
 symptomatic subfibular impingement, 201
 TMT injuries, 200
5-point K-L scoring system, 16

G
Garden III or IV fractures, 139

H
Hand arthritis
 artificial joint replacement, 97
 distal interphalangeal arthritis, 98–100
 prevalence, 97
Hemiarthroplasty, 50, 51
Hip
 management
  primary prevention, 33
  secondary prevention, 34
  tertiary prevention, 34

post-traumatic osteoarthritis
acetabular fractures, 31
hip dislocations, 33
osteonecrosis, 33
total direct cost, 35, 36
total indirect cost, 36, 37
Humeral resurfacing, 51
Hyaline cartilage, 21

I
ICD-10 coding system, 37, 38
Intercarpal and radiocarpal arthritis
management, 81–83
S4CF vs. *PRC*, 83, 85
scaphoid nonunion advanced collapse, 79
scapholunate advanced collapse, 78, 79
surgical technique, 88
total wrist arthrodesis, 86, 87
total wrist arthroplasty, 86
wrist denervation, 85, 86
International osteoarthritis research society (IOARS), 172
Interpositional arthroplasty, 66, 67
Intra-articular distal humerus fractures, 60
Intra-articular fractures, 28, 32
Isolated intercarpal arthritis
lunotriquetral arthritis, 89, 90
pisotriquetral arthritis, 90, 91
scaphotrapeziotrapezoidal arthritis, 89

J
Joint space narrowing (JSN), 16, 19

K
Knee
management
primary prevention, 28
secondary prevention, 29
tertiary prevention, 29, 30
post-traumatic osteoarthritis
anterior cruciate ligament injury, 27
intra-articular fractures, 28, 32
meniscal injuries, 27, 28
total direct cost, 35, 36
total indirect cost, 36, 37

L
Latency-associated peptide (LAP), 6
Lunotriquetral arthritis, 89, 90
Lunotriquetral interosseous ligament (LTIL), 75

M
Malleolar fracture, 18
Mayo Elbow Performance Index (MEPI), 66
Medial opening wedge osteotomy, 191
Medicare Severity Diagnosis-Related Groups (MS-DRGs), 38
Meniscal injuries, 27, 28
Mesenchymal stem cells (MSCs), 7
Metacarpophalangeal (MCP) joint arthritis, 103, 104

N
Non-inflammatory arthritis, 9

O
Osteoarthritic synovial system, 9
Osteoarthritis (OA)
atypical locations, 16, 17
pain and imaging findings, 21, 22
posttraumatic vs. idiopathic, 16
Osteocapsular debridement arthroplasty, 63–66
Osteochondral allografts (OCA), 173
Osteonecrosis, 33

P
Parathyroid hormone (PTH), 10
Patient-specific finite element stress analysis, 4
Pauwel III fractures, 139
Pipkin I fractures, 138
Pipkin III fractures, 138
Pipkin IV fractures, 136, 139
Pisotriquetral arthritis, 90, 91
Posttraumatic arthritis (PTOA)
arthroplasty, 143, 145, 146
core decompression, 145
epidemiology, 135, 136
femoral head fracture, 138, 139
femoral neck fracture, 139
hip arthrodesis, 146
hip arthroscopy, 143, 144
hip dislocation, 138
hip preservation, 144
intertrochanteric fractures, 141, 142
non-operative management, 143
pathophysiology, 136, 137
trochanteric fractures, 142
varus malunion, 145

Post-traumatic glenohumeral arthritis
  arthroplasty
    hemiarthroplasty, 50, 51
    humeral resurfacing, 51
    reverse shoulder arthroplasty, 51, 52
    total shoulder arthroplasty, 49, 50
  causes
    fractures, 46, 47
    instability, 47
    isolated chondral lesions/ osteochaondral injury, 48
  complications, 53
  non-arthroplasty surgery, 52, 53
  nonoperative management, 48, 49
  preoperative evaluation, 49
Proximal humerus fractures, 46
Proximal interphalangeal (PIP) joint injuries, 100–103
PTH type-I receptor (PTH1R), 11

R
Radial head and neck fractures, 60
Radiocapitellar arthroplasty, 67
Reverse shoulder arthroplasty, 51, 52

S
Scaphoid nonunion advanced collapse (SNAC), 79, 81
Scapholunate advanced collapse (SLAC), 78, 79
Scaphotrapeziotrapezoidal arthritis, 89
Subchondral bone
  functional unit, 5
  osteoarthritic, 6, 7, 10
Supramalleolar osteotomy, 191

T
Tibial plateau fractures, 32
  bicondylar fracture, 168
  classifications systems, 168
  CT imaging, 168
  genetic and environmental factors, 169
  incidence, 167
  ligamentous injuries, 168
  medial unicondylar fracture, 168
  meniscal injuries, 168
  posttraumatic osteoarthritis (OA)
    conservative treatment, 172
    ligamentous instability treatment, 168
    long-term outcomes, 168
    osteochondral allografts, 173
    osteotomies, 173, 175
    risk factors, 169
    total knee arthroplasty, 174, 177, 178
    unicompartmental knee arthroplasty, 174
  reconstructive surgery, 169
  soft-tissue injuries, 168
Total elbow arthroplasty (TEA), 68, 69
Total knee arthroplasty (TKA), 29
Total shoulder arthroplasty, 49, 50
Total wrist arthrodesis, 86, 87
Total wrist arthroplasty, 86
Transforming growth factor-beta (TGF-β)
  activation mechanism, 6
  articular cartilage
    functional unit, 5
    homeostasis, 10
    osteoarthritic, 7–9
  bisphosphonates, 10
  clinical effects, 10
  disease-modifying efficacy, 10
  function and behavior, 10
  isoforms, 5
  latency-associated peptide, 6
  osteoarthritic synovial system, 9
  parathyroid hormone, 10
  patient-specific finite element stress analysis, 4
  potential therapy, 10
  PTH upregulates BMP and Wnt signaling, 11
  Smad-dependent canonical pathway, 6
  subchondral bone
    functional unit, 5
    osteoarthritic, 6, 7, 10
  temporal-spatial regulation, 6
  type-I and type-II receptors, 6
Triangular fibrocartilage complex (TFCC), 77
Tricortical iliac crest bone autograft, 210

U
Ulnohumeral arthritis, 60

W
Wrist
  anatomy
    carpus and intercarpal joints, 74, 76
    distal radioulnar joint, 76

arthritis
distal radioulnar joint and ulnocarpal arthritis, 91, 92
evaluation, 77, 78
intercarpal and radiocarpal arthritis (*see* Intercarpal and radiocarpal arthritis)
isolated radiocarpal arthritis, 88
lunotriquetral arthritis, 89, 90
pisotriquetral arthritis, 90, 91
scaphotrapeziotrapezoidal arthritis, 89
denervation, 85, 86