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Staged Treatment and Associated Complications of Pilon Fractures

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Abstract

Historically, the treatment and outcomes related to pilon fractures have been variable despite anatomic reduction and fixation. Early results with treatment via early primary open reduction and internal fixation yielded mixed clinical outcomes, especially suboptimal complication rates, including infection, malunion, and nonunion. Treatment with external fixation also exhibited similar outcomes with mixed support reported in the literature. Despite continued controversy, the advent of newer implant technologies, improved surgical techniques, and management with a staged protocol have resulted in encouraging clinical outcomes with minimization of postoperative complications. Crucial decisions made during treatment can help to maximize outcomes while minimizing complication rates. Particular attention to the fracture pattern with radiographic guidance can help direct surgical decision making with appropriate care given to optimize soft-tissue status. A variety of available incisions can facilitate proper bony and articular reduction. During the late and failed stages of fracture management, additional treatment options include external ring fixation, arthrodesis, and arthroplasty. As complications arise, meticulous, prompt care can help to achieve the best possible outcomes.

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Named after its characteristic shape, the pilon or plafond fracture pattern is defined by intra-articular involvement of the distal tibia with metaphyseal extension.[1-3] Although pilon fractures account for only a small percentage of tibial and lower extremity injuries, more than 30% of pilon fractures are caused by high-energy injury mechanisms and are often associated with concomitant polytrauma with the presence of open wounds, degloving injuries, and severe soft-tissue trauma. These circumstances make injury management difficult.[4-9]

Historically, treatment involved early acute open reduction and internal fixation (ORIF), which led to dismal clinical outcomes and high complication rates[4,6,8,10-13] (**Table 1**). In

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Table 1
Summary Regarding Treatment and Complications for Pilon Fractures

Author (Year)	Management/Treatment	Number of Fractures	Reported Complications and Rates
Bourne et al[4] (1983)	Primary ORIF	42	Infection: 4.8% Nonunion/malunion: 33%
Teeny and Wiss[13] (1993)	Primary ORIF	60	Major complication: 50% (at least one of the following: skin slough, wound dehiscence, infection, nonunion, malunion, or implant failure)
Helfet et al[6] (1994)	Primary ORIF	34	Pin tract infection: 2.9% Deep infection: 5.9% Malunion: 8.8%
White et al[33] (2010)	Primary ORIF Within 48 hours: 98%	95	Wound dehiscence or deep infection: 6% Delayed or nonunion: 6%
Marsh et al[18] (1991)	External fixation (unilateral)	101	Reoperations: 5% Infection: 6% Loss of reduction during external fixation: 21% Malunion: 3%
Tornetta et al[19] (1993)	Limited internal fixation, hybrid external fixation	26	Superficial infection: 3.8% Deep infection: 3.8% Pin tract infection: 12% Malunion: 3.8%
Bone et al[16] (1993)	Delta-framed external fixation	20	Infection: 0% Delayed union/nonunion: 15% Malunion: 4.8%
Barbieri et al[15] (1996)	Hybrid external fixation	37	Skin slough: 2.7% Pin tract infection: 13.5% Deep infection: 8.1% Nonunion: 8.1% Loss of reduction during external fixation: 8.1%
Wyrsch et al[20] (1996)	Randomized controlled trial: primary ORIF versus external fixation (with and without limited internal fixation)	ORIF: 18 External fixation: 20	ORIF: wound dehiscence/infection: 67% amputation: 17% External fixation: nerve injury: 5% pin tract infection: 5% deep infection: 5% malunion: 5%
Anglen[14] (1999)	Comparative, ORIF versus hybrid external fixation (some soft-tissue optimization in both groups via temporizing external fixation)	ORIF: 19 External fixation: 29	ORIF: amputation: 5.3% skin slough: 5.3% sensory deficit: 5.3% External fixation: wire site infection: 24% half-pin site infection: 10.3% wound healing problems: 10.3% tethered flexor tendon: 3.4% nerve deficit: 3.4% nonunion: 21%
Sirkin et al[67] (1999)	Staged protocol, soft-tissue optimization	Closed: 30 Open: 19	Closed: partial-thickness skin necrosis: 17% osteomyelitis: 3.4% Open: wound dehiscence: 5.2% osteomyelitis: 5.2%
Patterson and Cole[31] (1999)	Staged protocol, soft-tissue optimization	22	Infections/soft-tissue complications: 0% Malunion: 4% Nonunion: 4%
Grose et al[5] (2007)	Staged protocol, soft-tissue optimization, lateral approach study	44	Deep infection: 4.5% Wound dehiscence: 4.5% Nonunion: 9%
Boraiah et al[69] (2010)	Staged protocol, soft-tissue optimization	59 (all open)	Amputation: 1.7% Deep infection: 3% Superficial infection: 5%

ORIF = open reduction and internal fixation.

an effort to minimize soft-tissue complications, limited approaches and treatments involving external fixation resulted in minimal improvement and generated little enthusiasm.[13-21] However, with the implementation of a delayed, staged surgical treatment protocol, along with improvements in imaging, implant technology, and surgical technique, complication rates have decreased with a coinciding improvement in clinical and functional outcomes.[5,7,9,22-32] Although it has been suggested that early definitive ORIF can achieve results comparable to those of staged protocols, it should be stressed that definitive ORIF should be performed by experienced trauma surgeons and may not be appropriate in all cases.[33] Experts have indicated that a delay in definitive treatment is necessary for some patients.[33] In the late and failed stages of treatment, options become more limited as complications, including infections, malunions, and nonunions, become more prevalent and difficult to manage. At this juncture, external fixation, ankle arthrodesis, and ankle arthroplasty become more viable options.[34-46]

This chapter reviews the current state of the decision-making process, staging, and the choice of surgical options for the definitive treatment of pilon fractures and associated complications, especially in the late and failed stages of fracture management.

Imaging and Classification

Initial assessment and thorough preoperative planning begins with radiographic imaging. Analysis of the fracture pattern is performed with the three standard views of the ankle (AP, lateral, and mortise), along with centered, orthogonal views above and below the joint, which are needed because of the high rate of concomitant polytrauma in patients with pilon fractures. Full-length tibia and fibula radiographs can provide information on general alignment.[2,4,9,10] In select patients, radiographs of the contralateral limb also can be helpful to provide a template for reconstruction for more complex pilon fractures and detect any preexisting anatomic or congenital variants that indicate a different "normal" baseline.

Theoretically, fracture classification systems are a tool for communication and providing information relative to treatment decisions and prognoses; however, to achieve those goals, the system must allow consistent, reliable, and reproducible classification of various fracture patterns. Rüedi and Allgöwer[12] offered the original foundation for pilon fracture classification, indicating three fracture types that increased in severity from low-energy, nondisplaced fractures of the tibia plafond to high-energy, severely comminuted and impacted articular fracture patterns. However, poor reliability and agreement have been reported.[47-49]

Based on plain radiographs alone, Martin et al[48] reported poor interobserver reliability of the Rüedi and Allgöwer classification system, with mean kappa values of 0.46 for all observers, 0.38 for more experienced observers, and 0.56 for less experienced observers. Similarly, Dirschl and Adams[47] reported a mean kappa value of 0.46, which indicated poor reliability. Removing the data from third-year residents resulted in a slight increase in the kappa value to 0.52.

Minimal improvements to classification agreement were observed with the development of the AO/Orthopaedic Trauma Association (OTA) classification system. Despite exhibiting higher reliability than the Rüedi and Allgöwer system, only moderate agreement between observers has been reported.[12,47,48,50] Regarding fracture type, group agreement, and subgroup agreement, Swiontkowski et al[50] reported only modest values, with agreement occurring 57%, 43%, and 41% of the time, respectively. Despite the use of CT, Ramappa et al[49] reported similar reliability and agreement values for both the Rüedi and Allgöwer and AO/OTA classification systems.

Realizing the inherent difficulty in stratifying outcomes based on unreliable classification systems, DeCoster et al[51] developed a rank order method, classifying patients based on injury severity and reduction quality. The results exhibited 94% agreement in ranking the severity of the articular surface, 89% agreement in ranking the severity of the fracture pattern, 89% agreement in ranking the reduction considering only the articular surface, and 88% agreement in ranking the reduction when considering the entire fracture pattern.

Although orthopaedic surgeons might not agree on the specific classification of the pilon fracture pattern presented, there is reliably high agreement on assessing the severity of the injury and in determining the quality of a poor or good fracture reduction.

Decision Making in the Initial Period

Management in the immediate period following a pilon fracture should focus on expedited medical optimization and clearance and soft-tissue stabilization. Important considerations include the presence of an open wound and/or a vascular injury.[52,53] A history of diabetes or smoking also may be a crucial consideration in decision making and in avoiding potential wound complications.[11,33,54,55] In patients with primarily indirect ankle fractures and complicated diabetes (diabetes associated with end organ damage), Wukich et al[56] reported a 3.8 times increased risk of overall complications and a

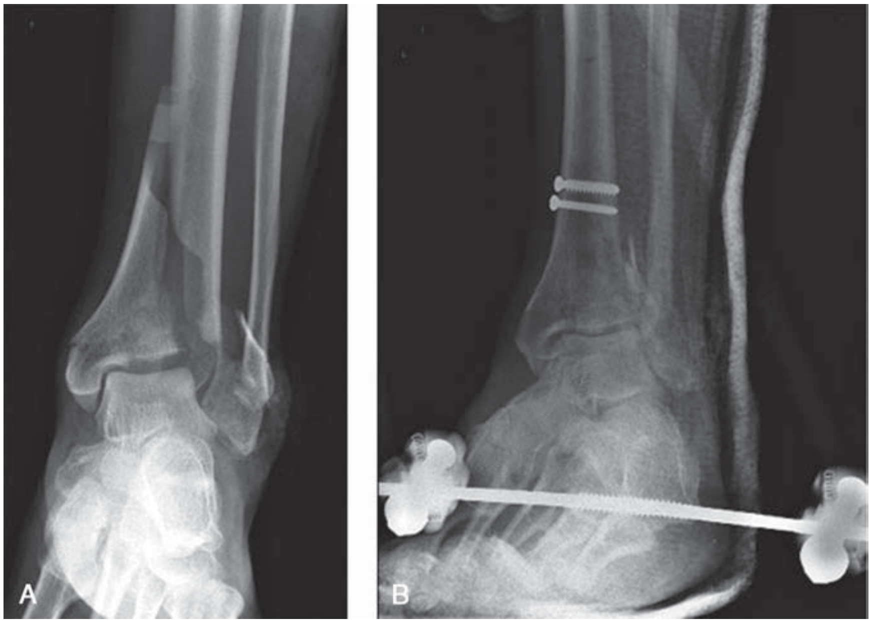

Figure 1 Preoperative (**A**) and postoperative (**B**) radiographs showing restoration of length, alignment, and rotation with ORIF to protect soft tissues, and simplify the pilon fracture for later definitive reconstruction.

5 times increased risk of revision surgery when compared with patients with ankle fractures and tightly controlled diabetes. A recent meta-analysis analyzing 6 randomized trials and 15 observational studies reported a significant decrease in total complications, wound complications, and pulmonary complications with prolonged smoking cessation.[55]

The amount of energy absorbed in the fracture is indicated by the degree of comminution, the Tscherne class of injury, and the presence of significant open wounds or a fibular fracture. The presence of a fibular fracture provides clues into the mechanism of injury and fracture pattern.[57] A fibular fracture typically is associated with higher energy injuries; however, if the injury is known to have been caused by a high-energy mechanism, the presence of the fracture contributes information on the direction of the mechanism (typically a valgus and an axial load).[57] Conversely, the absence of a fibular fracture or a tension failure of the fibula is associated with an injury pattern caused by a varus and an axial load.[57]

Following medical clearance and before definitive fixation, temporizing the extremity and restoring the mechanical axis, length, and alignment are pivotal to soft-tissue stabilization. Dunbar et al[58] described a technique that offered early, limited ORIF for AO/OTA type C fractures that typically present with a long, oblique metadiaphyseal spike. The authors presented data to suggest that early, limited restoration of length, alignment, and rotation with ORIF of the oblique fracture spike not only provides soft-tissue protection but also helps to simplify later definitive reconstruction without an increase in wound breakdown or complications (**Figure 1**).

It has been popularized that acute fibular fixation provides safe restoration of length in the initial period without an increased risk of complications.[7,53] However, preoperative planning, including determination of the "workhorse" surgical incision is of paramount importance, especially when considering additional incisions with an appropriate skin bridge.[7,33,59] Many surgeons have recommended a minimum 7-cm skin bridge to minimize soft-tissue and wound complications.[45,60,61] However, in a recent prospective study using at least two skin incisions with an average width of 5.9 cm, Howard et al[59] reported a low rate of soft-tissue complications in 42 patients with 46 pilon fractures. In essence, the "workhorse" incision is the main distal tibial incision that will allow definitive ORIF, even if smaller ancillary incisions are used.[7] However, it is important to understand that the ratio of the length of the incision to the width of the skin bridge is directly related to the soft-tissue complication rate.[7]

If the surgeon is unsure of the length of the "workhorse" incision or is not providing definitive treatment, it may be prudent to defer fibular fixation until an external fixator has been placed to restore the general mechanical axis and length and obtain a CT scan. In such instances, the application of a simple joint-spanning external fixator can achieve the initial goals and decrease the initial surgical time (**Figure 2**). This chapter's authors typically use a delta frame construct with two 5.0-mm pins in the tibial shaft placed out of the zone of injury and a 6.0-mm calcaneal transfixation pin in the posterior tuberosity of the calcaneus. Posterior splint supplementation or supplementary 4.0-mm metatarsal pins attached to the main delta frame can be used to maintain a plantigrade foot and avoid anteriorly prominent metaphyseal spikes of bone, which may cause deep soft-tissue pressure while waiting for definitive internal fixation.[7,13,15,16,18,19,61]

Knowledge gained during the past five decades makes it compelling to

Figure 2 A spanning external fixator can help achieve the initial goals of restoring the mechanical axis and length and stabilizing the bone as the soft-tissue swelling subsides.

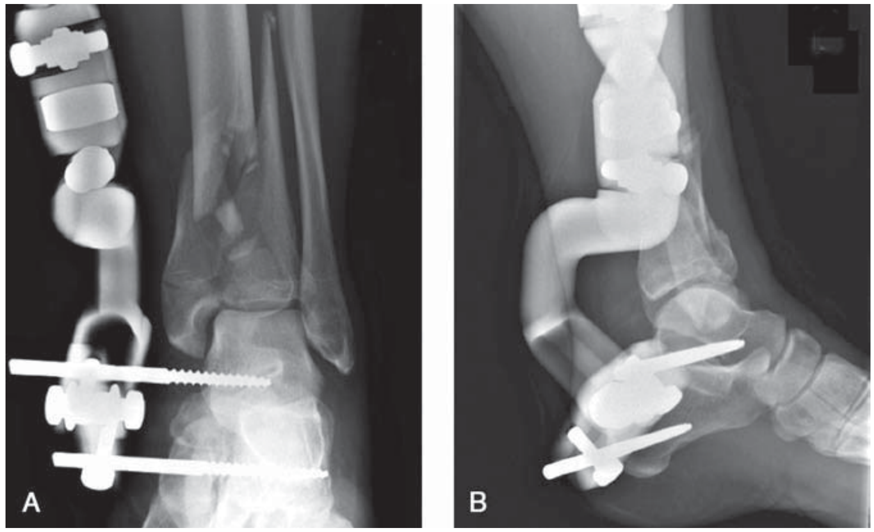

Figure 3 AP (**A**) and lateral (**B**) radiographic views of a pilon fracture after external fixation.

consider using multiple small incisions and staging definitive fixation procedures from the time of the initial external fixator application. This may require more than two total procedures based on the experience of this chapter's authors and is relative to the quality of the soft tissue. This may be the best method to decrease complications and potentially improve outcomes for patients with these injuries.

The anatomic placement of fixator pins is paramount. Proximally, pin placement should be just distal to the tibial tubercle to avoid the proximal metadiaphyseal extent of the zone of injury, which will require surgical manipulation at the time of the definitive procedure. Distally, pin placement may be transcalcaneal to construct a delta frame or medially through the talar neck and the medial calcaneus (**Figure 3**). The lateral plantar nerve, the most posterior lateral plantar nerve, and the medial calcaneal nerve should be avoided during transcalcaneal external fixator pin placement.[62] When considering medially based external fixators, close monitoring of the status of the medial talar neck pin is needed because infection in this pin may cause contamination within close proximity to the distal tibial incisions or the ankle joint.

Decision Making for Surgical Timing

It had been suggested that definitive surgical management within 6 hours of injury can be safe. However, on reevaluation and in the setting of high-energy injury mechanisms, ORIF undertaken in the acute period has yielded suboptimal results with high complication rates and poor clinical outcomes.[4,10-13,61] It has been shown that the risks of soft-tissue impairment caused by inflammatory processes is highest for up to 6 days after injury.[63]

Proponents of definitive external fixator constructs have cited slight improvements.[14-16,20] In a prospective, randomized study comparing external fixation to ORIF, Wyrsch et al[20] reported superior results in the cohort treated with external fixation; however, the ORIF cohort was operated on within 3 to 5 days of injury, whereas the external fixator cohort with limited open fixation was definitively treated more than 7 days after injury.[20] The importance of soft-tissue management has been emphasized.[64,65] The Tscherne soft-tissue classification system offers graded indicators of severe soft-tissue damage ranging from minimal superficial abrasions and degloving injuries to deep muscular and subcutaneous fat contusions, vascular injury, and compartment syndrome.[64] Despite determining two safe surgical windows—an early period within 6 hours after injury and a late period between 6 and 12 days after injury—surgery during this high risk period still exhibited consistently high complication rates and subpar clinical results.[13,20,64-66]

Staged management protocols have yielded improved results, with lower complication rates and improved clinical outcomes.[5,7,30,67] Sirkin et al,[7] using a staged protocol that consisted of acute external fixation and delayed definitive reconstruction, placed particular focus on soft-tissue optimization. The authors waited from 7 to 14 days for edema to subside, as indicated by subsidence with the presence of skin wrinkling.[7] Applying this staged protocol on the management of 56 pilon fractures, the authors reported two deep infections and the healing of all surgical wounds, which represented complication rates significantly lower than those of previous reports.[7,13,20]

The presence of blisters, which occur at a relatively high rate in pilon fractures, offer clues to the timing of definitive management.[20,68] In patients with blood-filled blisters, which indicate a complete separation of the dermis from the epidermis, Giordano and Koval[68] recommended waiting for full reepithelialization before surgical intervention. Resolution of edema is often indicated by the absence of shiny skin, with normal skin creases or wrinkles predominately exposed. Staging treatment and waiting for soft-tissue optimization has achieved favorable results in a more recent study that evaluated ORIF in open 59 pilon fractures.[69] Boraiah et al[69] reported excellent clinical outcomes at a minimum 2-year follow-up with 88% union and 9% delayed union, with only three deep infections, two superficial infections, and one amputation after a failed free-flap transfer.

Despite the success of the staged protocol, some surgeons remain proponents for early ORIF. White et al[33] performed ORIF within 48 hours in 95 patients with tibial pilon fractures and reported good clinical outcomes at 1-year follow-up. The authors reported an overall 19% complication rate in open and closed type C fractures and excluded fractures with "local soft-tissue factors" that were not specifically defined. In closed fractures, the complication rate was only 2.7%. Of note, the authors stress that the procedure must be done in "the right setting" and that all the resources must be available. They advise that early ORIF should not be done if resources are not available or if the patients present late or beyond an early treatment window. The authors suggest that medical judgment is needed.[33] It is important to note that the study included only patients who were deemed appropriate for the procedure; no guidance was provided on the criteria used to select suitable patients.

When planning for definitive fixation, CT is an invaluable tool. To best define the articular fragments and the definitive surgical approaches that may be required, this chapter's authors recommend that a CT scan should be obtained after external fixation is used to restore the length and mechanical axis of the extremity. Acquiring appropriate length with temporizing external fixation will disimpact the talus from the distal tibia and allow for better visualization of the articular injury.

Information on the specific areas of articular involvement, comminution, and impaction not seen on plain radiographs can be seen on CT scans[32] (**Figure 4,** *A* and *B*). Tornetta and Gorup[32] studied the impact of CT on the management of pilon fractures and reported that information from CT changed management decisions in 64% of the patients. The operating surgeons reported that information derived from the CTs bettered their understanding of the fracture pattern in 82% of patients and shortened the surgical time in 77% of patients.[32] Analysis of the surrounding soft tissues via soft-tissue windows on the CT scans also can provide valuable information, such as potentially entrapped tendinous or neurovascular structures (**Figure 4,** *C* and *D*).

Decision Making for Definitive Management

Over the past 40 to 50 years, the original principles set forth by Rüedi and Allgöwer[12] concerning pilon fracture management and reconstruction have not drastically changed.[70] The treatment algorithm, which emphasizes restoration of length with fibular reconstruction, reconstruction of the metaphyseal shell and articular joint, bone grafting, and a medial buttress to stabilize the metaphysis to the diaphysis reconstruction, still applies. Some advances in surgical approach options and implant technology have helped surgeons achieve those goals.[5,22,24,26-29,58,71]

Standard Approach

The standard approach to the tibial plafond is described as a two-incision technique—an anteromedial incision for the tibia and a posterolateral incision for the fibula.[12,70,72] However, depending on preoperative planning with CT identification of the major fracture fragments and lines and remembering to use an adequate skin bridge, additional surgical approaches can be used to maximize exposure and address specific articular issues.[7,27-29,32,59]

Anterior Approaches

Anterior approaches to the tibial plafond are based on the principle of reconstruction from posterior to anterior after "opening the book."[71-73] Use of the posterolateral (Volkmann) fragment as the "constant fragment" often relies on the assumption that the fibula was anatomically and stably reduced in terms of alignment, length, and rotation.[2,73] Each anterior approach (anteromedial, anterolateral, and direct anterior) has unique advantages and disadvantages.

With any of the anterior approaches, an external fixator or femoral distractor can be helpful to aid in evaluating and reducing articular fragments (**Figure 5**). It should be remembered that relative to the midsagittal plane of the tibia, the position of the transcalcaneal pin in a delta frame can

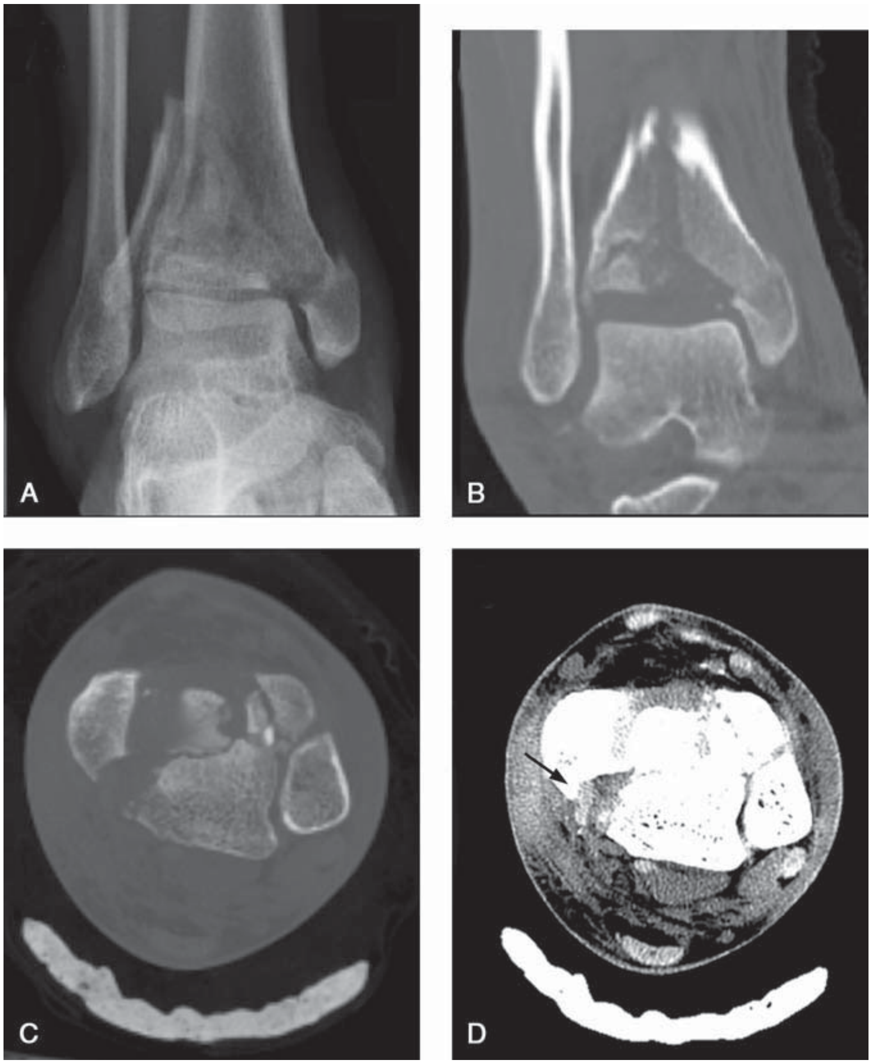

Figure 4 Surgical planning can be enhanced as degrees of comminution, impaction, or displacement not seen on a plain radiograph (**A**) can be seen on a CT scan (**B**). Bone windows (**C**) may be enhanced with soft-tissue windows (**D**), which may reveal entrapped tendinous or neurovascular structures such as the posterior tibialis tendon and flexor digitorum longus tendon (arrow).

cause a dorsiflexion moment of the foot with significant attempted distraction. This can inhibit direct visualization of the joint when there is significant anterior or central comminution. When the femoral distractor is applied with a pin in the talar neck and a pin in the tibia, a plantar flexion moment will yield excellent visualization of the joint; however, after the articular surface is stabilized, excessive distraction must be removed to allow appropriate reduction of the metadiaphyseal component that may have been deformed in the sagittal plane with the distractor. When applying the distractor, care must be taken to have the talar neck pin parallel to the superior dome of the talus to avoid "dialing-in" a coronal plane deformity.

Anteromedial Approach

The classic anteromedial approach described by Tile is typically used for AO/OTA type 43B and C fractures.[6,61,70,72,73] Starting approximately 5 cm proximal to the tibiotalar joint line and just lateral to the tibial crest, the anteromedial incision can extend distally to form around the medial malleolus or continue distally with the tibialis anterior tendon toward the talonavicular joint.[2,73,74] Care must be taken to avoid violating the tibialis anterior tendon sheath because, unlike the tendon itself, it will readily accept grafts (especially in the case of wound dehiscence).[75] Preservation of the periosteum in an already vascularly tenuous area is a high priority. Although this incision offers good access for medial and anterior hardware application, it does not allow ready access to the anterolateral (Tillaux-Chaput) fragment[71,73] (**Figure 6**).

Anterolateral Approach

The Böhler anterolateral approach to the tibial plafond allows direct access to the Tillaux-Chaput fragment left by the anteromedial approach.[22,27] Depending on concomitant foot and ankle injuries, the approach can be extended to provide direct visualization of the anterior talar dome and talar neck and lateral talonavicular, subtalar, and calcaneocuboid joints.[27] The incision is in line with the fourth metatarsal when the foot is in neutral dorsiflexion, and it starts 5 cm proximal to the tibiotalar joint.[27] Identifying and protecting the superficial peroneal nerve branches are imperative.[27] The origin of the extensor digitorum brevis is divided, reflecting it distally. The dorsalis pedis and the deep peroneal nerve are reflected medially, and the capsule is incised to provide access to the ankle joint. Herscovici et al[27] described this incision, noting that, if needed, the incision could be extended in both the proximal and distal directions with maintenance of straightforward closure and without an increase in wound complications. Although some surgeons have criticized the

Figure 5 With an anterior approach, a femoral distractor or an external fixator can assist in achieving length and visualization. However, important consideration must be paid to the potential plantar flexion moments (right arrow) or dorsiflexion moments (left arrow) when manipulating along the midsagittal axis (central line).

approach because of a lack of access to posterior fracture elements, Mehta et al[30] described successful total articular reconstruction with a bony distractor, headlamp, and intraoperative imaging via the anterolateral and a second more medially based incision. Grose et al,[5] using an alternative extensile approach from the lateral plafond and crossing medially to reach the anterior, reported good results and low complication rates, especially regarding deep infection (4.5%) and wound dehiscence (4.5%).

Direct Anterior Approach

The direct anterior approach can provide access to both the anteromedial and anterolateral fragments of a pilon fracture with a straightforward linear incision centered over the tibiotalar joint. The approach is centered between the malleoli, with protection of the superficial peroneal nerve. The incision is developed between the extensor digitorum longus (EDL) and extensor hallucis longus (EHL), with

Figure 6 The anteromedial incision offers access for medial and anterior hardware application, but does not allow ready access to the anterolateral (Tillaux-Chaput) fragment.

protection of the deep neurovascular bundle using medial retraction. Traditionally used for ankle arthrodesis, the direct anterior approach can be used to treat pilon fractures and, if necessary, for future fusion (**Figure 7**). In a recent retrospective review of 49 pilon fractures, McCann et al[76] reported low complication rates with minimal soft-tissue disturbance with the direct anterior approach.

Posterior Approaches

Posterior approaches to the pilon are used in select situations when the goals cannot be accomplished using the anterior approaches. Of note, direct articular reduction is not possible and relies on cortical reduction and fluoroscopic assistance.[29,65,77] Benefits of the posterolateral incision are its use in rebuilding the constant fragment, especially if it has significant impaction and/or rotation[2,29,73] (**Figure 8**). Rebuilding the constant fragment also can convert a C-type fracture to a B-type fracture. The surgeon can use an anterior approach to rebuild the plafond from posterior to anterior.[58] Attention must be given to correcting the sagittal plane deformity of articular fragments because direct joint visualization is not possible with the posterior approach; the surgeon must rely on fluoroscopic and direct cortical readings.

Posterolateral Approach

The posterolateral approach, which exploits the interval between the lateral and the posterior compartment musculature, was believed to offer a lower complication rate;[2,29,73] however, Bhattacharyya et al[77] noted a high complication rate with this approach, including nonunions and wound healing problems leading to fusions and suboptimal clinical outcomes. Of note, the authors attempted complete fixation tibial pilon fractures through the one surgical approach.[77] When required, the posterolateral tibia can be addressed between the peroneus longus and the flexor hallucis longus, while the fibula can be addressed posteriorly by going anterior to the peroneus brevis.

Posteromedial Approach

The posteromedial approach is helpful when treating tendon or neurovascular bundle entrapment.[28] The incision is made at the midpoint between the medial malleolus and the posteromedial aspect of the Achilles tendon. Identification of the tendinous and neurovascular structures is paramount to allow safe development of intervals based on the fracture pattern. Using both a posteromedial and a posterolateral approach on the same patient should be done with caution because of the relative proximity of the approaches and the need for extensive deep surgical dissection. Typically, most of the posterior aspect of the distal tibia can be addressed through either approach; the area requiring more direct manipulation should be chosen. In select situations when a small window is required

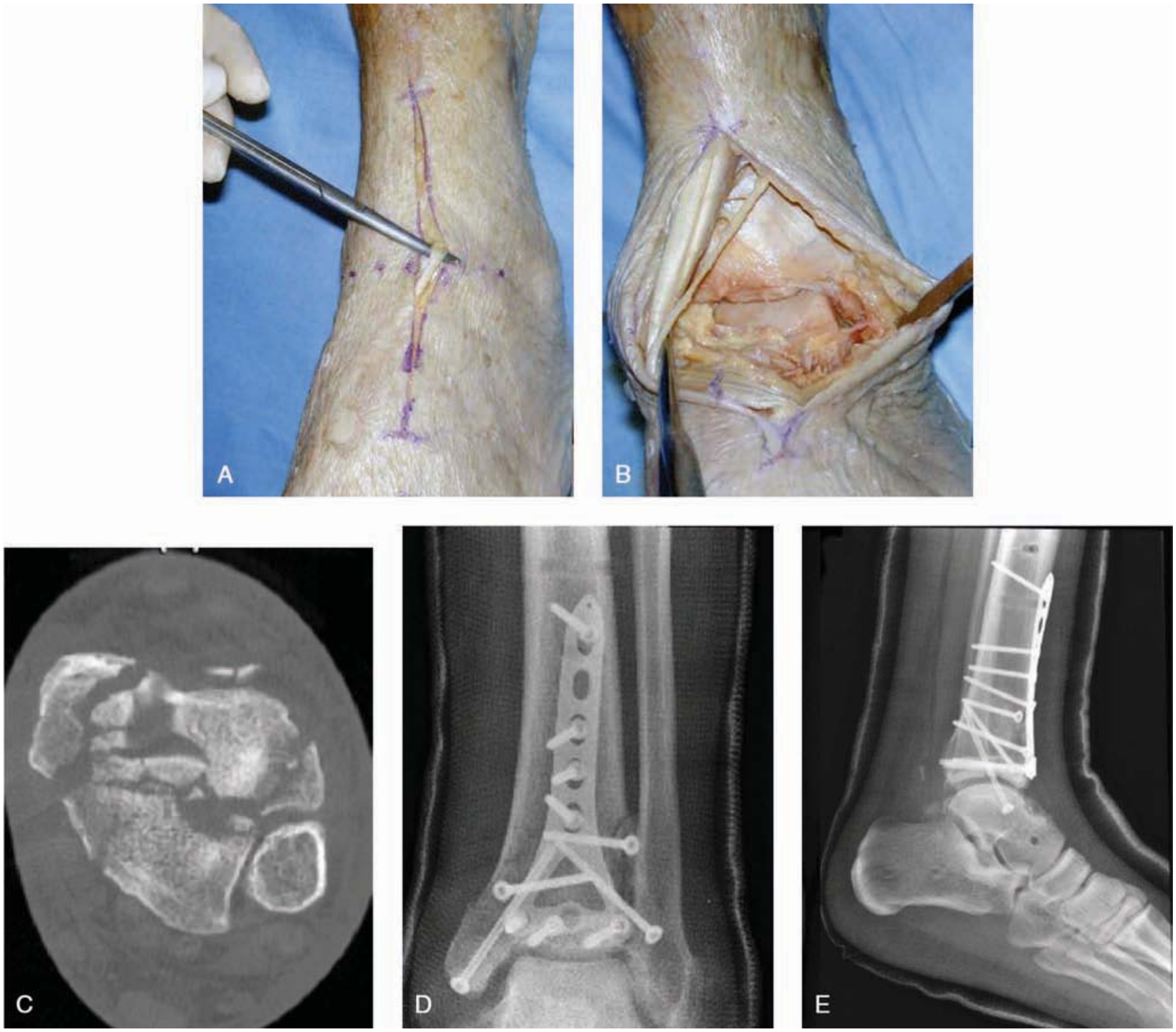

Figure 7 The direct anterior approach can be used to treat pilon fractures. **A,** An incision should be made at the center of the mortise, providing access to the anteromedial and anterolateral aspects of the joint. The branches of the superficial peroneal nerve should be avoided, and the extensor retinaculum should be incised. **B,** Intervals include the EHL/tibialis anterior, EHL/EDL, and the EDL/peroneus tertius. Note that proximal to the tibiotalar joint, the neurovascular bundle lies between EHL/tibialis anterior but distal to the tibiotalar joint. The bundle lies between the EHL and the EDL. The anterior ankle capsule and the intra-articular fat is excised to expose the joint. **C,** At times, the fracture pattern and location can dictate the use of a direct anterior approach. AP (**D**) and lateral (**E**) radiographs of definitive ORIF via a direct anterior approach. Using the direct anterior approach can help facilitate future ankle fusion if needed.

for the placement of a reduction aid, the use of both approaches can be considered.

Discussion

The multitude of surgical approaches and advancements in small fragment, mini-fragment, and bioabsorbable fixation have provided improvements in specifically treating articular fragments in previously unreconstructable fractures.[22-25,28,29,53,78] Locking-plate constructs may obviate the need for bone grafting in select patients and provide added stability in patients with comminuted fractures or osteoporosis.[2] Such fixed-angle constructs can help decrease the number of plates required based on the fracture pattern and comminution while providing adequate stability to allow for protracted healing.

Future implant modifications may further improve the clinical results.

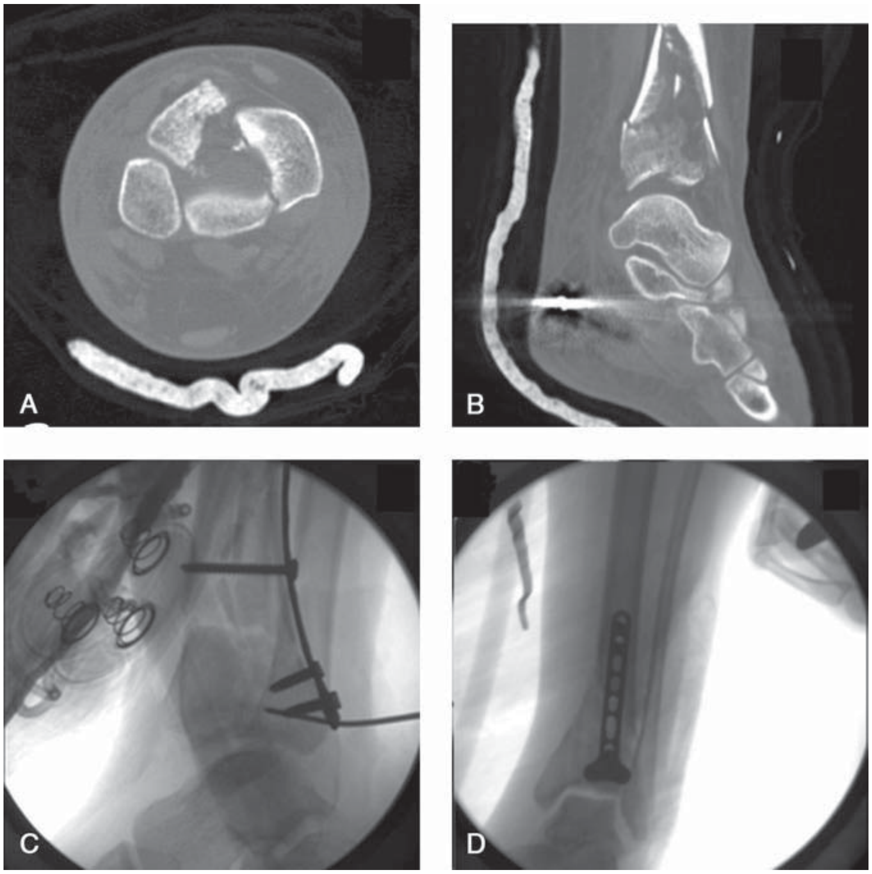

Figure 8 **A** and **B,** The posterolateral incision allows for reconstruction of the constant fragment, especially if it has significant impaction and/or rotation. Derotation (**C**) and rebuilding (**D**) of the constant fragment with limited fixation can act as a bridge to staged anterior ORIF.

The role of intramedullary nailing (IMN) for pilon fractures has not been extensively studied. In a study of the results of IMN for distal tibial fractures, Vallier et al[79] found complication and union rates comparable to plating. When considering limited ORIF with IMN for fixation of fractures of the plafond, careful study of the CT scan and understanding the fracture is imperative. Stable articular reduction and independent screw fixation are required, while leaving access for appropriate placement of an IMN. This technique is recommended only for simple articular fractures without impaction when performed by an experienced surgeon. The metaphyseal defects should be addressed primarily with bone graft to limit the risks for nonunion.[40,80] However, in select patients with "unreconstructable" pilon fractures, severe soft-tissue injuries, or significant comorbidities precluding safe direct fixation, external ring fixation can be considered.

External Ring Fixation

The application of external ring fixation for pilon fractures requires careful patient selection, extensive knowledge of fixation constructs, familiarity with the ring fixation system being used, comprehensive knowledge of the cross-sectional anatomy, and diligent postoperative maintenance.[41] External ring fixation can serve as a limb-salvage technique in scenarios where extensive internal fixation is not an option and thus should be used judiciously.[34,81]

External ring fixation for pilon fractures is indicated if the patient is not amenable to standard stable internal fixation or in the setting of combined limited ORIF.[46,81,82] Ring fixation is best suited to patients with severe soft-tissue injuries who are not candidates for plastic reconstructive surgery, such as free vascularized muscle transfers or rotational flaps. Ring fixation is also an excellent modality for late reconstruction and salvage of pilon fractures with segmental bone loss, infection, and preexisting deformity.[83] Advantages of ring fixation in pilon fracture management include earlier weight bearing, the ability to make postoperative frame adjustments, better soft-tissue management, and no complications relating to retained hardware.[84]

Many parts and components must be assembled to build a stable construct. Pilon fracture frames will typically consist of two rings. The proximal ring should always be placed above the zone of injury, which can be in the proximal third of the tibia. This ring can be stabilized to bone with bicortical half pins or fine wires. The entire inner surface of the ring should be at least 3 cm from any skin or soft tissue to allow adequate expansion after swelling. Half-pin and thin wire placement techniques are of utmost importance. Improperly placed pins and wires will result in loosening, soft-tissue infection, and potentially even osteomyelitis. A small stab incision large enough to allow placement of the drill tip, followed by careful drilling of both cortices of bone is imperative. Bone should not be drilled so aggressively as to allow smoke or burnt bone. Irrigation and cleaning of the drill flutes should be done frequently to prevent necrosis of the bone around the edge of the hole. Once the proximal ring has been fastened to the half pins, the distal ring may be applied around the fracture. The metaphyseal bone is often not amenable to half-pin fixation secondary to comminution and bone destruction. The distal segments therefore are held by thin wires at an optimal 60° angle from one another. If internal fixation of the joint is not used, the articular surface can be reduced and stabilized with olive wires. The olive wires are tensioned from one side and create a vector of force that compresses the bone fragments together (**Figure 9**). Similarly, olive wires and smooth wires can be used to suspend the metaphyseal bone and the joint surface under the diaphysis in the correct anatomic and mechanical axis.

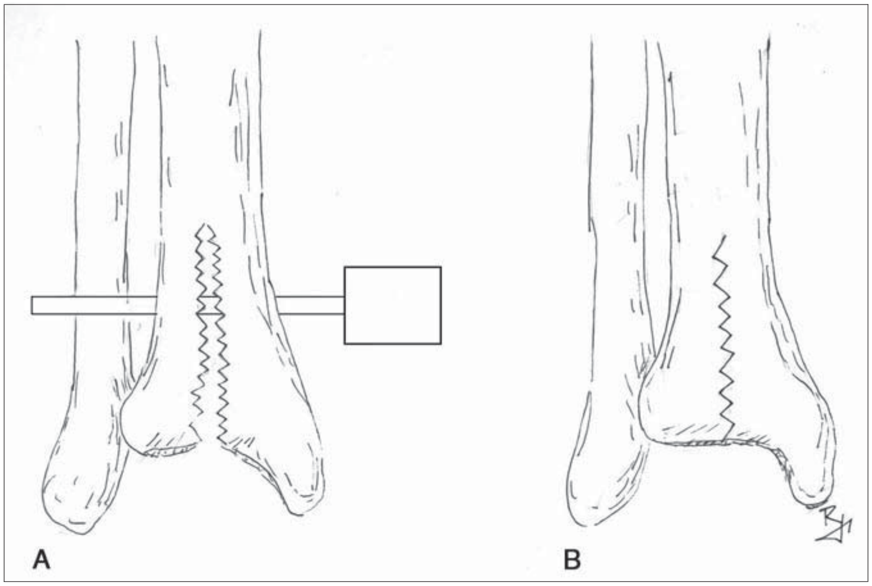

Figure 9 **A,** Olive wires can be tensioned from one side using a tensioner (shown as box) to create a vector to assist in bone compression. **B,** The bone after compression.

Regardless of the decision to fix the joint either with minimal internal fixation or with wires alone, it is always necessary to perform an open reduction of the joint with the goal of anatomic reduction. In cases where there is severe comminution of the joint and metaphysis and fixation with thin wires is tenuous, the application of a foot plate can be helpful. The foot plate is connected to the distal ring, and the hind foot and forefoot are connected to the foot plate using thin wires and olive wires. The foot should be held in a plantar-flexed position, especially during application of the forefoot wires.

Many ring fixation systems offer 0.5 rings and 0.625 rings that can be used to afford access to soft tissue and allow movement of the ankle joint. For example, a 0.625 ring can be placed with the open portion over the dorsum of the foot, thus allowing the patient to dorsiflex the ankle without impinging on the ring. Similarly, a ring opening can be oriented to allow access to a suture line, a traumatic wound, or a muscle flap.

Delicate, meticulous management in the postoperative period following ring fixation is crucial to a successful outcome. Compressive dressings are applied, and the patient is kept on bed rest for 48 hours, with strict elevation of the extremity. Intravenous antibiotics should continue for 24 hours postoperatively, and appropriate thromboembolic prophylaxis should be used. On postoperative day 2, pin care should begin. Daily showering of the external fixator with soap and water followed by scrubbing the pin sites with povidone iodine or chlorhexidine is safe and effective. Hydrogen peroxide is not recommended for pin care. Weight bearing in the frame should take place only after there is radiographic evidence of union of the articular fracture, which can occur as early as 8 weeks. Close follow-up in the first 6 to 12 weeks is necessary to prevent pin tract infections and noncompliance with frame maintenance.

Initially, radiographs should be made every 2 to 4 weeks to ensure that there is no loss of reduction or migration of wires through comminuted bone. To prevent loss of a pin or a wire, pin tract infections should be treated with oral antibiotics, with coverage for staphylococcus, and monitored closely. In infections that are recalcitrant to oral antibiotics, pins and wires should be removed to prevent the development of osteomyelitis. If a frame is needed for more than 3 months, at least one pin or wire should be removed during the course of treatment. Despite the scarcity of data, with meticulous care and proper management, external ring fixation can provide a viable treatment option in the setting of salvage, a pilon fracture with severe soft-tissue injury, or in the late or failed stages of definitive fracture management.

Decision Making for Managing Complications

There are many potential complications resulting from the surgical treatment of tibial pilon fractures.[45,85] Early complications of the definitive management of pilon fractures include surgical wound dehiscence, postoperative infection, malreduction, and loss of fixation.[45] Late complications include chronic infection, nonunion, malunion, and posttraumatic arthritis.[45] Infection is potentially the most devastating complication.[86]

In the early postoperative period, the most common wound complication is superficial surgical wound necrosis without dehiscence.[45,87] This condition can be treated with standard local wound care and soft-tissue rest with temporary splint or cast immobilization. If associated with wound erythema, there may be a role for systemic oral antibiotics. Wound culture of the partial thickness skin slough is not generally indicated and will likely result in only normal skin flora being isolated. Close observation of the wound is required to expeditiously identify a deep wound infection.[86]

If a surgical wound dehiscence is identified, the patient should be treated with urgent surgical débridement.[86] The tenuous soft-tissue envelope surrounding the distal tibia often makes reclosure of the surgical wound unlikely. The wound should be cleansed, deep cultures taken, and the stability of the fracture implants assessed. Although grossly loose and incompetent implants should be removed, bone stability is critical to controlling the integrity of the soft tissues, and competent hardware should be retained. There may be a role for negative-pressure wound management if the surgical wound cannot be fully approximated.[45]

Deep wound infection also requires surgical treatment, frequently with serial irrigation and débridement procedures performed every 48 to 72 hours until no further purulence is identified and no devitalized or necrotic tissue is present.[45,87] Negative-pressure wound management or local antibiotic therapy with impregnated polymethyl methacrylate beads is used in combination with systemic antibiotic therapy based on the findings from the wound cultures. Typically, systemic antibiotics are given for 6 weeks, followed by serial erythrocyte sedimentation rate and C-reactive protein analyses to guide the appropriate duration of the therapy. Definitive soft-tissue management with rotational or free-tissue transfer may be needed; a surgeon familiar with such procedures should be consulted early in the treatment process to appropriately coordinate the reconstruction.[88]

Late or chronic infections after pilon fracture surgery are generally associated with osteomyelitis and contaminated surgical implants.[45] The implants usually cannot be retained if successful sterilization of the bone is to be achieved. All devitalized and necrotic bone should be removed. Cortical saucerization with a high-speed burr should be performed, and a thorough bony débridement may require reaming of the intramedullary canal. Large bony defects may be filled with an antibiotic-impregnated cement spacer.[45,87] In rare instances of gross osseous instability, hardware may be exchanged or retained; removal of the hardware with spanning external fixation also can be considered until the infection has subsided and definitive internal fixation can be reapplied.

Malunions or nonunions after pilon fracture surgery may pose complex reconstructive problems.[86,89] The deformity must be characterized and understood. Is the deformity extra-articular or intra-articular? What is the sagittal and coronal alignment? Is there a rotational malalignment? What is the relationship of the tibial articular surface to that of the distal fibula? What is the degree of axial shortening? It is also important to evaluate the soft-tissue status around the distal tibia, and it is critical to assess the viability (salvageability) of the joint. Often, the articular surface of the pilon fracture has united, and the nonunion or malunion is largely extra-articular. If the articular surface is reasonably well aligned, an extra-articular correction of the deformity or nonunion may be performed. The choice of correcting such a deformity in a single stage or by gradual correction will be determined by the integrity of the soft tissues and their tolerance to surgical intervention. The selection of nail fixation, plate fixation, or external fixation should be made with consideration of the distance of the deformity from the articular surface, the viability of the bone at the nonunion/malunion site, the patency of the medullary canal, and the effect on the bone of prior implants and surgeries. Resultant bone defects after the correction of the deformity may require treatment with morcellized or structural bone grafts. Large complex deformities, particularly in compromised soft tissues, may be best treated with gradual correction and distraction osteogenesis.

The treatment of intra-articular malunion or nonunion requires a careful assessment of the viability of the ankle joint. Well-positioned radiographs and CT are used to assess the congruence of the joint surfaces and the degree of union between fracture fragments. MRI may be used to assess the degree of articular damage and chondral injury but is less useful when there is retained hardware from a prior fracture or nonunion surgery. Staging arthroscopy may be used to evaluate the chondral surface in circumstances where other diagnostic imaging studies have failed to provide sufficient information for surgical planning and decision making. Joint mobility and the degree of soft-tissue contracture around the ankle must be carefully assessed. Correction of bony deformity without soft-tissue balancing is likely to lead to a poor outcome. Achilles tendon lengthening and the release of joint contractures may be done either as part of the surgical approach or as a separate part of the procedure. In difficult situations, bony union may have to be achieved first and a secondary subsequent soft-tissue surgery performed later; however, the treatment of both components simultaneously is generally preferred.[45,90]

In general, the treatment of intra-articular nonunion or malunions after pilon fracture is generally reserved for partial articular fractures[76] (**Figure 10**). The correction of a complete articular nonunion, while possible, is generally exceedingly difficult because the vascularity of each articular fragment must be maintained during the osteotomy, realignment, and fixation. Partial articular nonunions or malunions require osteotomy and mobilization of the displaced articular fragment and reduction of the articular surface (**Figure 11,** *A*). There may be resultant gaps in the articular reconstruction, but the goal is to provide a congruent joint surface with as minimal a residual irregularity as possible (**Figure 11,** *B* and *C*). Stable interfragmentary compressive fixation is required and is often supplemented by buttress plate fixation (**Figure 12**). Intercalary allograft or tricortical autograft may be necessary if stable fixation cannot be achieved by compression alone.

The most common long-term complication after a tibial pilon fracture is posttraumatic arthritis.[45,85] Radiographic findings of posttraumatic arthritis may not always correlate with the patient's symptoms or reported disability. The initial management of the symptomatic patient should include nonsteroidal anti-inflammatory drugs, shoe wear modification, or activity modification. A heel lift may provide some initial relief to the patient with limited dorsiflexion caused by anterior tibiotalar osteophyte formation. A rocker-bottom sole or an Arizona brace may provide symptomatic relief

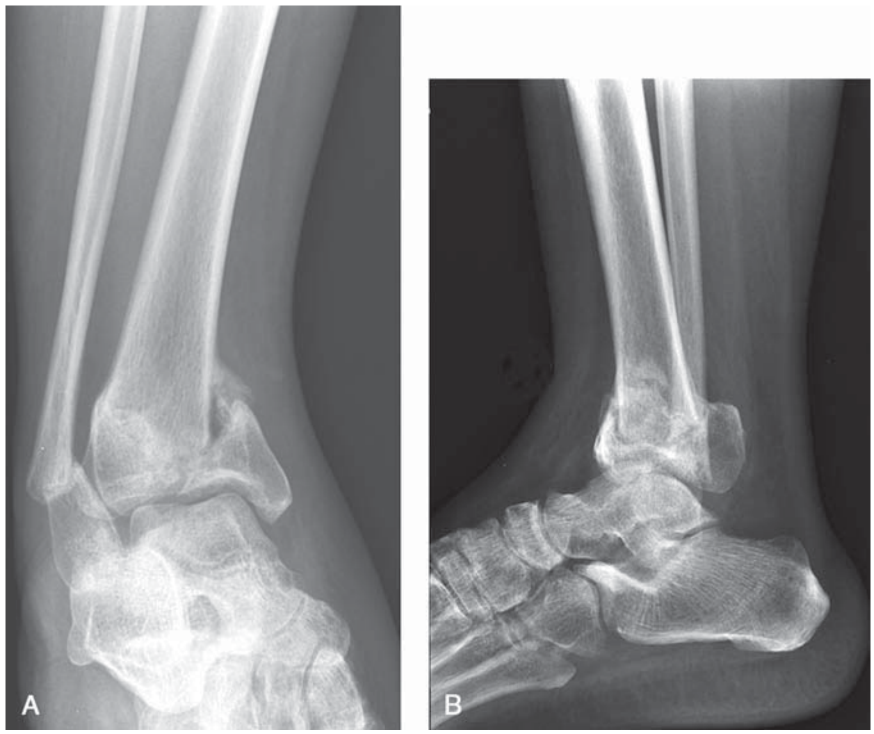

Figure 10 AP (**A**) and lateral (**B**) radiographs of a pilon fracture malunion 7 months after the initial injury.

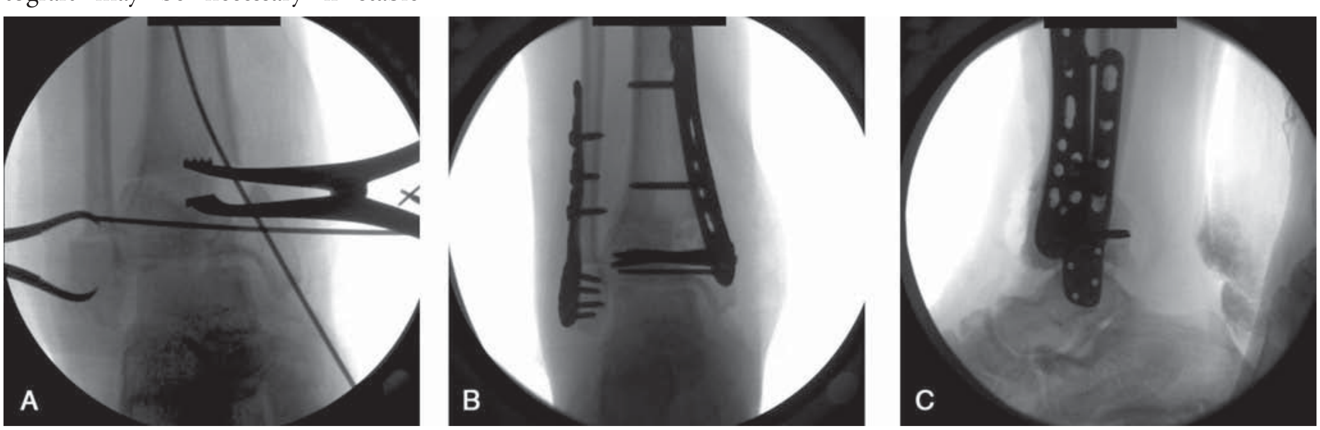

Figure 11 **A,** Intraoperative fluoroscopic view of the restoration of alignment and the articular joint surface. AP (**B**) and lateral (**C**) intraoperative views of definitive ORIF.

Figure 12 AP (**A**) and lateral (**B**) radiographs of a pilon fracture at 3-month follow-up with corrected and articular alignment.

Figure 13 AP radiograph following ankle arthrodesis for posttraumatic arthritis 2 years after definitive ORIF for a pilon fracture.

for the relatively stiff, painful ankle. Intra-articular steroid injections may provide temporary symptomatic relief but are typically used sparingly. Arthroscopy generally plays a role only in the patient with symptomatic impingement; the resection of anterior osteophytes may temporarily relieve symptoms and improve ambulation.[45] The long-term results are uncertain. Although distraction arthroplasty with or without fascial interposition has been advocated, there are no large series reporting long-term relief of symptoms with this technique.[45]

The most reliable treatment of end-stage posttraumatic ankle arthritis is arthrodesis[35,36,38,39,91] (**Figure 13**). This is generally performed as an open procedure because of the presence of previously placed fracture hardware. Retained implants are generally removed, erosions or subchondral cysts are grafted, and the deformity is corrected to establish proper position for foot placement. Generally, the recommended position for arthrodesis is with a plantigrade foot, slight hindfoot valgus, external rotation equivalent to the patient's contralateral limb, and a translation of the talus posteriorly under the plafond to improve gait mechanics. Motion in the subtalar joint and midtarsal joints should be preserved if possible, and a careful assessment of arthritic changes, particularly in the subtalar joint, should be performed. Selective injection of the subtalar joint as a diagnostic procedure may help the surgeon determine whether radiographic changes in the subtalar joint are sufficiently symptomatic to warrant treatment at the time of ankle arthrodesis. In posttraumatic situations, the surgical approach and the technique for arthrodesis is generally determined on the basis of prior incisions, the compromise of soft-tissue flaps, the location of previously placed implants, and any residual deformity.[39] The presence of infection and osteonecrotic bone may necessitate a staged procedure with removal of the implants, débridement, and placement of an antibiotic spacer followed by second-stage definitive arthrodesis.[35] Arthrodesis in the presence of significant deformity may require acute shortening to avoid soft-tissue coverage. Subsequent limb lengthening may be performed if the resultant limb-length inequality is unacceptable to the patient. Alternatively, gradual deformity correction may be combined with the arthrodesis and limb lengthening with of the use of multiplanar external fixation and distraction osteogenesis.[92,93]

Short- and intermediate-term outcomes are generally good after arthrodesis, with patients reporting a significant reduction in pain and improvement in gait; however, the development of symptomatic degenerative arthritis in the subtalar, transverse tarsal, and midtarsal joints may be reported with long-term follow-up.[36,39] Patients almost universally report functional limitations secondary to pain.[35,36,39,91]

Ankle arthroplasty is another option for the treatment of symptomatic posttraumatic ankle arthritis.[37,43,44] It is generally reserved for patients with minimal deformity, a healthy soft-tissue envelope, and no history of prior infection.[94] Vascularized bone, a healed fracture, and minimal residual implant defects are considered prerequisites for this procedure.[94] Many surgeons recommend a staged treatment protocol for these injuries, with initial removal of the hardware, a biopsy to rule out infection, and an assessment of bone viability followed by a second-stage definitive arthroplasty. The results of total ankle arthroplasty for posttraumatic arthritis are generally inferior to those of arthrodesis.[44] In most studies, an increased incidence of major complications is generally reported after arthroplasty, and satisfaction is equivalent to that after arthrodesis.[43] The major reoperation rate for complications after the procedures is substantially higher after arthroplasty, although the need for subtalar arthrodesis has been reported to be lower.[44] At the present time, most authors generally do not recommend total ankle arthroplasty over arthrodesis for posttraumatic ankle arthritis after a pilon fracture. It is hoped that continued improvements in implant design and longevity will lead to improved outcomes and expanded indications for the procedure.

Ankle arthrodesis remains the mainstay of treatment of the failed pilon fracture. Osteotomy and joint salvage of the nonunited or malunited fracture is an uncommon situation and is generally reserved for partial articular injuries or those in which the articular surface has united in a reasonable position. The role of arthroplasty is uncertain and remains investigational, with longer term follow-up required to arrive at a definitive, efficacious conclusion.

Summary

Even though staged protocols and advancements in technique and technology have evolved, the original principles regarding pilon fracture management remain unchanged. Restoration of length with fibular fixation, reconstruction of the articular surface, bone grafting, and buttressing of the metadiaphyseal reconstruction remain the foundation of optimal management. Treatment modifications include a better understanding of the importance of soft-tissue management, with particular focus on soft-tissue edema and blister resolution. Strategic preoperative planning with the use of CT and selection of appropriately bridged surgical incisions may facilitate an easier perioperative period and desired postoperative outcome. To stage the subsequent incision, the surgeon who provides definitive treatment should initiate the first "workhorse" incision. Knowing the pros and cons of each surgical approach will improve the chances of achieving the desired clinical results. Future protocol changes, implant technologies, and the role of IMN in the management of pilon fractures may be the subjects of further research, but the principles of pilon restoration will most likely remain the same. External ring fixators are complicated but are viable options for treating unsalvageable, severely injured pilon fractures and are a useful tool for fracture management in the late and failed stages of treatment. Treating complications requires careful attention to wound management to avoid infection, malunion, and nonunion. If complications arise, arthrodesis remains the mainstay of management. The efficacy of ankle arthroplasty awaits improved clinical and longer term survival data.

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