Review Article

Pilon Fracture: Preventing Complications

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Abstract

Fractures of the distal tibial plafond (ie, pilon) comprise a broad range of injury mechanisms, patient demographics, and soft-tissue and osseous lesions. Patients often present with considerably comminuted fracture patterns and notable soft-tissue compromise. Surgical intervention must be performed with respect for the exceedingly vulnerable soft-tissue envelope and with a properly executed technique. Even with proper timing, favorable host factors, and expert surgical technique, restoration of function and avoidance of complications are not always achievable. Recently validated techniques further diminish the risk of soft-tissue and osseous sepsis. These techniques include early (ie, "immediate") fixation, upgrading, primary arthrodesis, staged sequential posterior and anterior fixation, acute shortening, and transsyndesmotic fibular plating. Proper application of these recently adopted techniques may be instrumental in achieving aseptic union of pilon fractures.

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Tibial pilon fractures represent a wide array of osteoarticular, metaphyseal, and soft-tissue compromise. The mechanism of injury is equally broad. The combinations of articular comminution and meta-diaphyseal osseous deficits may prove therapeutically challenging. Circumferential soft-tissue compromise is common, and it may predispose the patient to complications such as infection and nonunion if proper timing and surgical approach are not carefully contemplated. Proper management of both the osseous and soft-tissue element of the injury is required to obtain favorable outcomes. Restoration of function while avoiding catastrophic complications is the primary treatment objective.

In 1969, Rüedi and Allgower,[1] who were dissatisfied with nonsurgical management of intra-articular fractures of the distal tibia, described favorable results achieved with surgical fixation. They advocated the use of several treatment principles, including lateral column restoration, medial column buttressing, and autogenous bone grafting in combination with articular reconstitution. Their study consisted of a cohort of lower-energy injuries for which wound healing complication rates were deemed within acceptable parameters. Adopting these principles, other investigators witnessed concerning rates of infection.[2,3] These higher-energy lesions were, accordingly, associated with more complicated pathoanatomic characteristics.

Aseptic restoration of the articular surface and limb alignment should be predictive of both restored function and the avoidance of pain. The surgical methods used to achieve articular reduction have, however, generated conflicting results. Variables such as mechanism of injury, host factors, and patient demographics may be more predictable determinants of outcomes. DeCoster et al[4] investigated the influence of injury severity and quality of reduction on the outcome. They concluded that although the quality of reduction offered a notable correlation with radiographic arthrosis, it did not independently correlate with the functional outcome.

High infection rates and wound-healing complications following traditional surgical reduction have prompted refinement of less-invasive methods of osteoarticular reconstruction. Methods of minimizing the risk of infection associated with traditional plating techniques have evolved. Hybrid external fixation, which is characterized by early minimally invasive articular reconstruction neutralized by transarticular external fixation, initially appeared to be an attractive alternative to traditional plating techniques. Although deep infection rates were diminished with external fixation, articular malreduction and metadiaphyseal malalignment proved difficult to overcome and were associated with less desirable outcomes.[5-7] Studies seeking to compare this method of treatment with traditional plating techniques had considerable design flaws. The compromised results of these hybrid constructs nurtured the tactic of staged treatment. This approach emphasized soft-tissue recovery with initial application of a spanning external fixator. Definitive fixation was completed only after the soft tissues were receptive (ie, resolution of swelling, regional abrasions, and blisters). This fixation was performed with the inclusion of strategically positioned surgical approaches and, where applicable, minimally invasive methods of implant insertion. Several studies demonstrated efficacious management of high-energy lesions using delayed surgical intervention in this staged fashion and reported predictable and favorable outcomes.[8,9] Adopted protocols emphasized meticulous soft-tissue management in combination with delayed definitive fixation to offer diminished additional compromise to surrounding soft tissues. Short- and long-term outcomes demonstrated a reduction in surgical complications. Despite adherence to contemporary staged protocols, a relatively high complication rate may still exist. The evolution of biologically benign methods of reduction and plate fixation has served to further diminish complication rates. This trend is most evident with regard to wound healing and subsequent development of superficial or deep infection.

Early Primary Fixation

Optimal timing for surgical management of pilon fractures remains controversial. Early transarticular external fixation followed by delayed internal fixation is one management option; however, several authors have advocated early primary open reduction and internal fixation (ORIF) as a viable strategy for managing both open and closed pilon fractures.

White et al[10] studied a cohort of 95 patients with AO Orthopaedic Trauma Association (OTA) type 43.C pilon fractures, most of whom had been treated with primary ORIF within 48 hours of injury. They reported that deep infections requiring surgery occurred in 6% of patients. However, patients with "local soft-tissue factors" such as gross contamination and the presence of hemorrhagic fracture blisters were excluded from the cohort. At a minimum 1-year follow-up, the authors of the study assessed the quality of fracture reduction and functional outcomes. Compared with the use of delayed strategies, these authors observed enhanced anatomic fracture reduction and similar functional outcomes with ORIF. They concluded that even high-energy pilon fractures within their cohort could be predictably and effectively managed with ORIF. However, they acknowledged that early fixation may not yield acceptable results in patients with notable regional or systemic comorbidities (ie, alcohol abuse, schizophrenia, diabetes, peripheral neuropathy, hemorrhagic fracture blisters) and discouraged surgical intervention between 3 and 5 days after injury. These investigators further advised that adopting this strategy demands the refined skills of an orthopaedic traumatologist with sufficient resources and access to the operating room.[10]

In a retrospective comparative study, Tang et al[11] reported similar results with early fixation of closed pilon fractures. These authors studied two groups of 23 patients, all with closed AO OTA type 43.C pilon fractures. Group A was treated with early fixation (ie, within 36 hours) using minimally invasive techniques, and group B was treated with delayed fixation. They excluded all open fractures, injuries with AO soft-tissue grades of ≥4, patients with compartment syndrome, and patients with diabetes, cancer, or immunodeficiency. The overall infection rate was 17.4%, and there was no significant difference between the two groups. These authors, however, included superficial wound infections that did not require surgical intervention in their analysis. They reported no deep infections in the immediate fixation group and one deep infection in the delayed fixation group. Additionally, they reported statistically significant reduction in the surgical time and length of hospital stay for patients treated with early fixation ($P < 0.01$ for both).[11]

We have observed similar success (particularly with regard to ease of reduction) but have used this strategy with caution. Our experience has been limited to closed fractures, usually in patients who have sustained isolated injuries. Typically, we

Figure 1

A B

A, Intraoperative photograph showing an open tibial pilon fracture in a 22-year-old man who presented 36 hours after initial injury from an outside hospital with a steel wire wound closure and a Penrose drain, and without a transarticular external fixator. The patient was treated with a temporizing spanning external fixator and serial débridement. He subsequently underwent internal fixation, antibiotic bead placement, and definitive wound coverage. Elective autologous bone grafting and bead extraction were performed several months later. **B**, Postoperative AP radiograph obtained 12 weeks after initial injury showing early consolidation of callus.

advocate the pursuit of early definitive fixation only under the direction of an orthopaedic traumatologist and in cases in which patient status and resources permit intervention within 12 hours.

Open Pilon Fractures

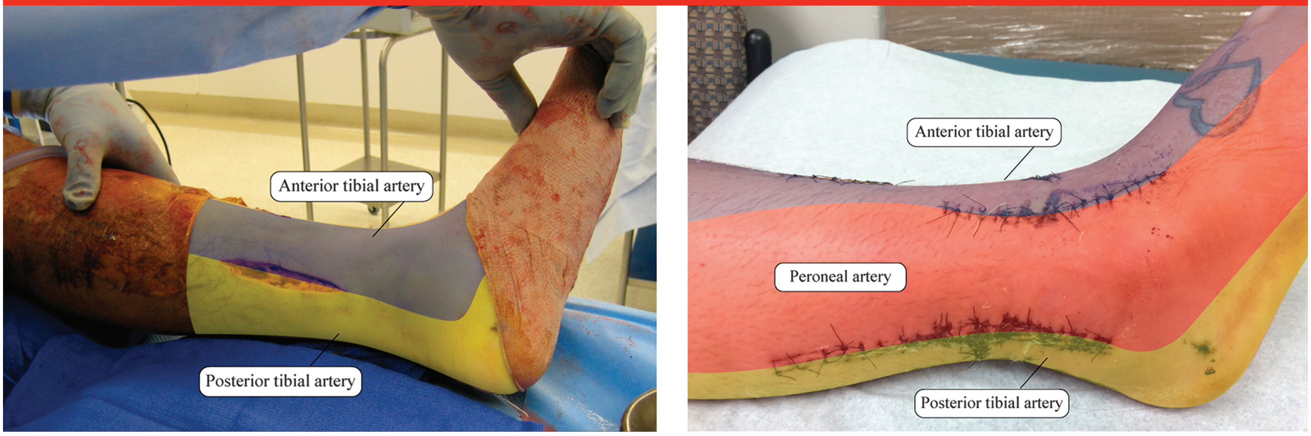
High-energy pilon fractures, particularly those with associated open lesions, often present with deficient osteoarticular components and marginally salvageable metaphyseal components. Failure to recognize and address metadiaphyseal deficits, even in the absence of infection, may predict failure. Threatened regional soft tissues and a considerably heightened risk of infection pose a therapeutic dilemma. The outcome of high-energy pilon fractures does not solely depend on the integrity of regional soft tissues and the osseous elements. In addition, it is very much influenced by individual patient characteristics such as social history, regional, and systemic comorbidities.

LeBus and Collinge[12] assessed vascular abnormalities in high-energy tibial plafond fractures with CT angiography. Their data analysis suggested that open fractures were far more likely than closed variants to be associated with arterial abnormalities. They further concluded that no other injury characteristics offered substantial correlation with arterial injury. They did not, however, witness notable postoperative wound-healing abnormalities despite vascular compromise (predominantly injury to the anterior neurovascular bundle). They contended that their success was likely due to the use of temporizing external fixation and minimally invasive techniques with delayed surgical intervention. Preserved collateral blood flow was suggested to compensate for arterial deficiency.

Typically, multiple surgeries are required to address both articular and metaphyseal insufficiency in these open lesions. They remain fraught with complications and the potential for quiescent or obvious infection, either of which may be overwhelmingly refractory. Gardner et al[13] adopted a successful protocol to manage open pilon fractures with results yielding favorable outcomes and an acceptable infection rate. The first stage focused on immediate débridement of devitalized osseous and soft-tissue elements in addition to the application of a temporizing ankle-spanning external fixator (Figure 1, A). Adequate débridement with eradication of all devitalized tissues, both soft and osseous, was emphasized. These débridement efforts were performed through traumatic wound extensions or anticipated subsequent surgical incisions. After recovery of soft tissues (usually within 1 to 3 weeks) and in the absence of obvious signs of infection, soft-tissue coverage was next performed with inclusion of antibiotic bead placement and contemporary plate fixation. Several months later, elective bone grafting was performed with bead extraction (Figure 1, B). This third stage was performed only in the presence of resolved edema and in the absence of drainage or clinical signs of infection.

Boraiah et al[14] evaluated a staged protocol to address open fractures of the pilon in an effort to minimize soft-tissue complications and subsequent infection. They acknowledged that restoration of limb alignment, rotation, and anatomic articular reconstitution when managing these lesions may minimize the evolution of posttraumatic arthrosis. They further cautioned that surgical goals toward articular reconstitution should not be pursued at a cost to regional soft tissues, owing to the potential for disastrous outcomes. Sanders et al[15] similarly observed that, in severe open pilon fractures, the required

Figure 2



A B

Intraoperative photographs showing the medial (**A**) and lateral (**B**) aspects of the lower leg in two different patients, with the three angiosomes roughly delineated. Posteromedial (**A**) and anterolateral and posterolateral (**B**) approaches were performed between the angiosomes, thereby limiting risk to the resultant skin bridge.

adequate débridement of soft and osseous tissues may result in considerable segmental bone loss and articular deficits. The authors were able to achieve satisfactory outcomes in a small cohort of patients using immediate surgical arthrodesis of the ankle joint. Their analysis confirmed the feasibility of limb reconstruction in such scenarios. Results, however, were of questionable value. They advised that patients be forewarned of the expected multiple surgical procedures, lengthy hospital admissions, and substantial imposition on vocational and personal relationships. Furthermore, they argued that primary amputation in select cases may prove to be the "conservative" treatment of choice.

Surgical Approach and Infection

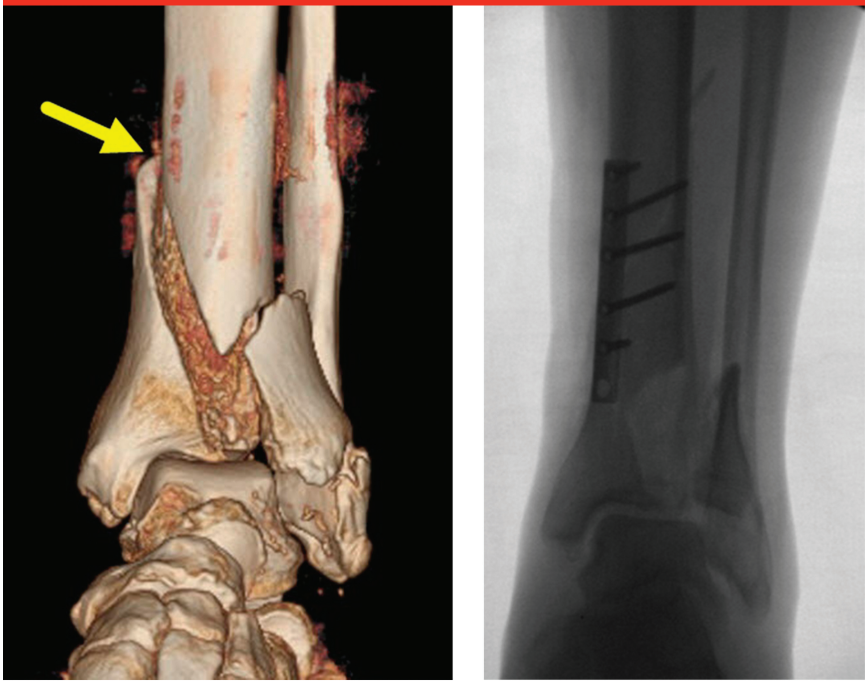
Numerous surgical access strategies have been offered, each with unique limitations, attributes, and characteristics. Various combinations of approaches have been described, as have concerns regarding their proximity to one another. Howard et al[16] sought to ascertain the validity of a commonly held conception that a 7-cm skin bridge must be maintained between surgical incisions around the ankle joint. They suggested that adherence to this unconfirmed 7-cm dogma was not required if proper soft-tissue management and appropriate timing of surgical intervention were maintained. They further suggested that the pattern of injury, not skin bridge dimension, should dictate surgical approach selection. In most of their retrospectively reviewed cases, a skin bridge of <7 cm was observed, and soft-tissue complication and infection rates were acceptable. The anterolateral (Böhler) approach, in particular, has proven resilient when combined with either medial or posterolateral approaches.[17] Despite infrequent dehiscence, superficial infection, and eschar, it has proven to be receptive to and requiring of only local wound care and healing by secondary intention.

Three vertically oriented angiosomes exist, supplying the overlying soft-tissue envelope of the lower leg and ankle.[18] Surgical incisions placed in parallel between the angiosomes pose no threat to the resultant skin bridge (Figure 2). The skin bridge and the source vessels in the overlying cutaneous blood supply appear tolerant of this. This is in sharp contrast to the risks posed by transverse incisions. The technique of deep surgical dissection, perhaps more than the proximity of the incisions to each other, has the greatest influence on wound healing and evolution of infection.

Minimally Invasive Fixation

Although the combination of multiple incisions and their proximity to each other was described earlier, the attributes of minimally invasive techniques have been explored and adopted by some surgeons. Submuscular anterolateral (Böhler) approaches cannot be used with purely percutaneous efforts because regional neurovascular structures remain at risk.[19] Several studies have sought to assess the efficacy of minimally invasive subcutaneous instrumentation methods to address pilon fractures and associated wound healing complications.[20,21] Such efforts are largely limited to medial column restoration using percutaneous techniques. In a

Figure 3



A B

A, Three-dimensional CT scan demonstrating proximal apical extension (arrow) of a pilon fracture pattern in continuity with a peripheral large articular implant. **B**, Intraoperative AP fluoroscopic image showing fixation of the apical portion of a pilon fracture with an oblique extension encroaching proximally on the diaphysis using a proximal posteromedial approach remote from anticipated subsequent more peripheral approaches.

cadaver study, Borrelli et al[22] described the extraosseous blood supply of the tibia and the effect various forms of plate fixation have on it. Percutaneously introduced plates seemed to cause less disruption to the extraosseous blood supply, particularly in the medial aspect of the distal tibia. Subsequent studies have validated these findings from a clinical perspective.[23,24] In contrast, Lau et al[25] observed a concerningly high rate of late superficial infection, primarily with medial subcutaneous plates. They maintained, however, that this had little effect on the outcome. These infections were successfully managed with a brief course of antimicrobial therapy and, on occasion, implant extraction. Other studies have demonstrated similar findings with regard to medial wound healing complications.[20,26] Most of these were easily resolved without notable negative effects on osseous union or functional outcome. Although minimally invasive methods of fixation demonstrated diminished rates of infection, obstacles remained. Among these, nonunion, malreduction, and angular deformities were not uncommon.

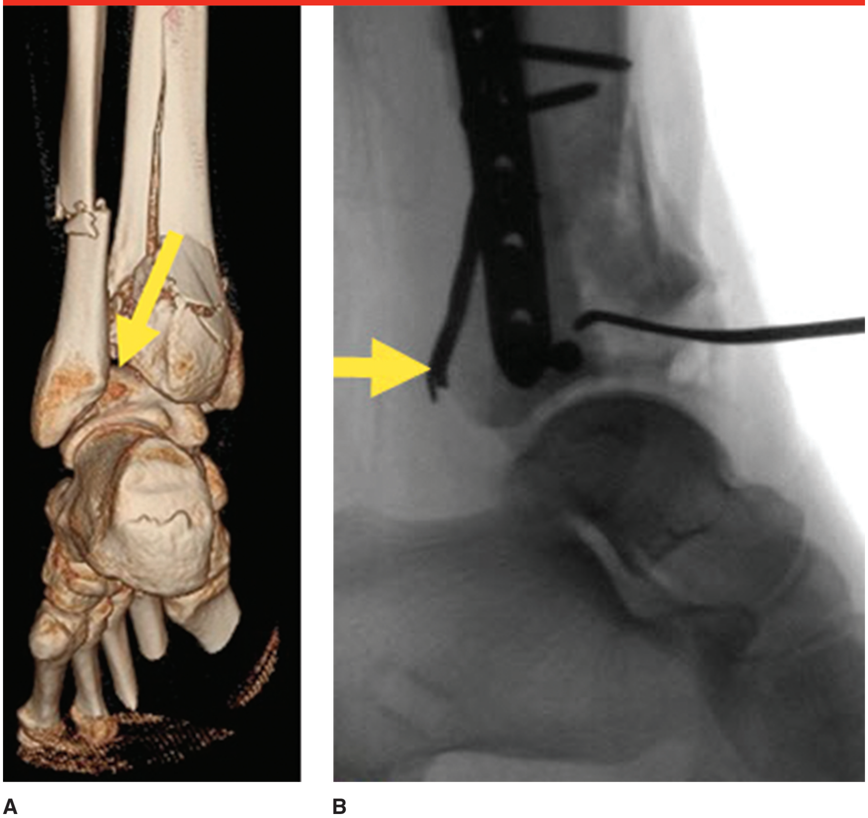
Upgrading

When managing soft-tissue concerns in an effort to reduce the risk of infection, the concept of upgrading, in which a complex fracture pattern is converted to a simpler one, may have a role. Dunbar et al[27] identified a subset of pilon fractures presenting with an oblique extension that encroached on the diaphysis proximally (Figure 3, A). They suggested that these lesions were challenging from the standpoint of acceptable reduction when managed in a delayed fashion. The authors maintained that delayed management of these lesions required excessive stripping, greatly impaired reduction of these fragments, and compromised anatomic restoration of the articular surface. They proposed that this fracture pattern could be more expeditiously managed in the acute setting during surgical débridement and application of a transarticular fixator. In accordance with this technique, small fragment plates were applied to the diaphyseal component of the fracture, typically in an antiglide fashion, through small proximal incisions (Figure 3, B). Avoidance of tenuous peripheral soft tissues was required, and additional osteoarticular reconstruction was deferred until soft-tissue status permitted. This served to reestablish length, rotation, and alignment of these regional fragments, which were commonly in continuity with either the anterolateral (Chaput) or posterolateral (Volkmann) articular fragments. Early anatomic restoration of these fragments (through upgrading) afforded a foundation for subsequent delayed definitive fixation. When applied to pilon fractures, the technique of upgrading enables conversion of an AO/OTA type C (ie, complete articular involvement) pattern to an AO/OTA type B (ie, partial articular involvement) pattern. Despite being performed in the acute setting, it served to diminish subsequent soft-tissue compromise during the course of definitive fixation. This, in turn, diminished the risk of infection and subsequent wound compromise. The offered technique seems to be simple and safe, and it is an adjunct to prevent infection. It does, however, warrant further investigation and cautious application.

Sequential Fixation

The limitations of traditional anterior exposures with the patient supine have proven challenging with regard to the reduction of associated posterior malleolar patterns. These important posterior components, when accurately reduced, may serve as a useful template for restoration of the fracture length, angulation, and articular reconstitution. Soft-tissue detachment, in addition to comminution and small fragment dimensions, may make traditional surgical exposures inadequate in achieving required anatomic reduction (Figure 4, A). The resultant malreduction may prohibit subsequent articular reconstitution. Ketz and Sanders[28] recognized potential difficulties encountered during the course of reduction of the posterior malleolar fragment associated with high-energy pilon fractures. In select fracture patterns, the advantages of direct posterior malleolar plating performed with prone patient positioning were readily apparent. These investigators adopted a staged protocol with initial application of an external fixator combined with a limited posterior open reduction through a posterolateral approach. This exposure was permitting of concomitant fixation of the fibula. They acknowledged the limitations of articular scrutiny during the course of posterior fragment fixation efforts, which were indirectly reduced. Caution was urged with regard to execution of fibula fixation because any element of malrotation, shortening, or angular malalignment could prevent anatomic reduction of the posterior fragment. After recovery of soft tissues, a delayed second staged surgical intervention was performed to reduce and fixate the remaining anterior fragments to their now intact posterior fragment counterparts (Figure 4, B). This staged protocol permitted early surgical access (posteriorly) through soft tissues, with subsequent fixation performed anteriorly. Surgical fixation through the more compromised anterior soft tissues required considerable delay. Katz and Sanders[28] reported improved articular reductions and better functional outcomes compared with previous protocols of delayed single-stage definitive fixation. There were no increased complications associated with wound healing. As described previously, this served to upgrade the lesion to a pattern of lesser complexity with potentially more predictable subsequent reduction maneuvers. This protocol, in accordance with upgrading techniques (despite early surgical intervention to receptive soft tissues), hastened the recovery of peripheral soft tissues. This staged strategy of fixation may reduce wound healing complication rates and the risk of infection.

Figure 4

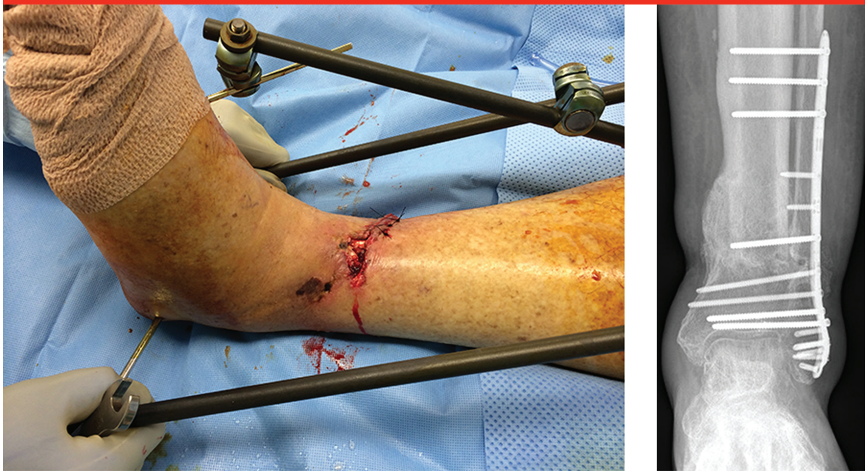


A, Three-dimensional CT scan showing a posterior pilon variant with syndesmotic detachment (arrow). The syndesmotic detachment may complicate reduction efforts when anterior approach strategies are used with the patient in the supine position. **B**, Intraoperative lateral fluoroscopic image demonstrating a posterior antiglide plate (arrow) that was placed through a posterolateral incision to restore an intact posterior column on which additional reduction and fixation may be executed. This foundation facilitates delayed, anteriorly based approach and fixation.

Transsyndesmotic Fixation

On occasion, concerns regarding the integrity of the soft tissues and host characteristics may exceed osseous concerns. Low-energy fracture variants with primarily medial compounding wounds in patients with considerable comorbidities are not uncommon. Sciadini et al[29] reviewed

Figure 5



A B

A, Intraoperative photograph demonstrating a high-energy open pilon fracture in a 67-year-old man. The patient presented with concerning regional and systemic comorbidities. He was deemed a poor candidate for medial soft-tissue reconstruction efforts. Conventional fixation efforts may have further complicated recovery of soft and osseous tissues. **B**, AP radiograph of the ankle showing transsyndesmotic fixation of the pilon fracture. Deliberate shortening was performed, further facilitating wound closure and uneventful wound healing medially. Bony union was achieved without adjuvant surgical or grafting efforts.

several cases of distal tibial fractures with minimal or no articular involvement but with notable medial soft-tissue injury. These authors described a novel approach of fixed angle transsyndesmotic fixation, which offered minimal introduction of surgical insult, particularly to compromised medial soft tissues. Such constructs have been previously described to enhance fixation in patients with diabetes and osteoporotic ankle fractures of low complexity and energy. The greatest utility of the technique is in the management of valgus distal tibial fractures with associated medial traction wounds. Sciadini et al[29] proposed this technique as a viable method of obtaining and maintaining reduction with or without the sustained application of a transarticular external fixator. Their cohort included patients with high-energy injuries, including falls from a height and vehicular injuries. Medial soft tissues were not receptive to minimally invasive plate fixation of the medial column. Transsyndesmotic fixation is perhaps most suitable when conventional methods of fixation may pose unacceptable risks to anterior or medial soft tissues. Fixation is introduced through the less traumatized and more resilient lateral soft tissues.

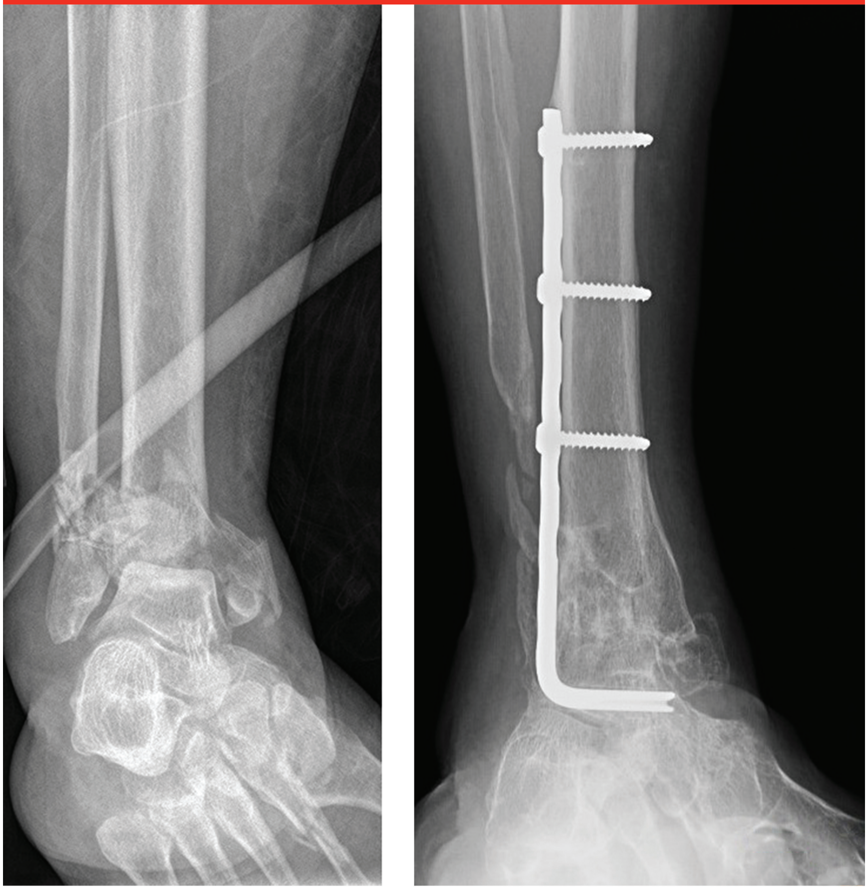
Technical aspects of transsyndesmotic fixation include the use of a fibular plate with hybrid fixation techniques. Transsyndesmotic locking screws are placed in the distal limit of the fibular plate, engaging the distal tibia in a quadricortical fashion. Bicortical fibular or similar quadricortical fibular-tibial screws are introduced proximally. This construct serves to bridge the tibial component of the fracture pattern. Preferred constructs use a long precontoured distal fibular plate. We have found that this construct is indicated for patients with valgus patterns who are deemed poor candidates for complex soft-tissue coverage. Most of these patients have preexisting medical and regional comorbidities. In addition, we have found that this technique is appropriate for deliberate, acute shortening efforts (Figure 5). When indicated in patients in whom complex soft-tissue coverage is not appropriate, shortening may facilitate wound closure. It is a potentially useful strategy in the surgeon's armamentarium to avoid disastrous wound healing complications and subsequent infection.

Primary Ankle Arthrodesis

Although the relationship between the quality of reduction and functional outcome measures may offer some correlation, an exception may be fracture patterns with extreme comminution and metadiaphyseal impaction. Numerous studies have sought to ascertain the influence of the fracture pattern and surgical treatment selection on the quality of reduction and functional outcome of surgically managed pilon fractures. Anatomic osteoarticular reconstruction in the setting of severe comminution is challenging, with no guarantee of favorable outcomes. Furthermore, reconstruction may result in a severe threat to soft tissues and infection; thus, a role for primary ankle arthrodesis may exist (Figure 6). Arthrodesis permits cautious delayed treatment, which allows recovery of soft tissues.

Several studies have assessed the role of primary arthrodesis in the setting of severe articular comminution that precluded anatomic reconstitution. Beaman and Gellman[30] demonstrated reliably good outcomes with anterior plate fixation supplemented by a neutralizing external fixator with primary arthrodesis of the ankle. These authors, encouraged by expedited patient recovery, suggested the use of primary ankle arthrodesis to manage complex patterns that are refractory to osteoarticular reconstitution. Acceptable healing rates were reported, with good overall functional scores. Zelle et al[31] reported satisfactory results with the application of a posteriorly applied blade plate. They described it as a reliable method of addressing a small subset of injury patterns that are deemed nonreconstructable. Primary arthrodesis is indicated for management of fracture patterns with extensive comminution and marked impaction of the articular cartilage (>50% of the tibial plafond delineated on preoperative CT) within the tibial metaphysis. The authors reported good results, even in the setting of metadiaphyseal deficits. Zelle et al[31] advocated the use of primary arthrodesis in select patients and highlighted the reduced rate of infection compared with infection rates associated with conventional fixation techniques. The authors did acknowledge the preferential goal of articular reconstitution when possible, in an effort to limit midfoot arthrosis, which is a complication commonly associated with otherwise successful tibiotalar arthrodesis.

Figure 6



A B

A, AP radiograph of the ankle of a 67-year-old woman who sustained a pilon fracture in a high-energy motor vehicle collision. The articular component was deemed nonreconstructable, and the soft tissues were severely compromised. A temporizing transarticular external fixator was applied for 4 weeks, and then primary ankle arthrodesis was performed. **B**, AP radiograph of the ankle after primary arthrodesis with a lateral blade plate.

Acute Shortening

The combined presence of soft tissue and osseous deficits complicates management of severely comminuted pilon fractures, particularly those with associated metadiaphyseal comminution. Soft-tissue reconstruction options include local rotation flaps, skin grafts, and free flaps. In patients deemed poor candidates for such procedures, acute shortening of the distal fracture site facilitates closure of the traumatic wound and may simultaneously address osseous deficits.

Unintended shortening upon application of a temporary transarticular external fixator is not uncommon when managing open pilon fracture variants. The wound is often perceived as easily coapted during débridement. For simple fracture patterns, subsequent anatomic restoration may result in a readily apparent diastasis of the traumatic wound, necessitating soft-tissue coverage. We have successfully performed intentional shortening with the inclusion of posterior plating techniques in patients deemed poor candidates for soft-tissue transfer (Figure 7). This management option requires segmental osseous resection (ie, tibia and fibula), intraoperative vascular monitoring, and acceptance of limb shortening. The advantages of acute shortening include shorter hospital stay and avoidance of complicated soft-tissue reconstruction, both of which reduce the cost of care. The posterolateral approach has been described by some as less prone to wound healing complications than other approaches.[32,33] Others, however, have not found this to be the case.[34]

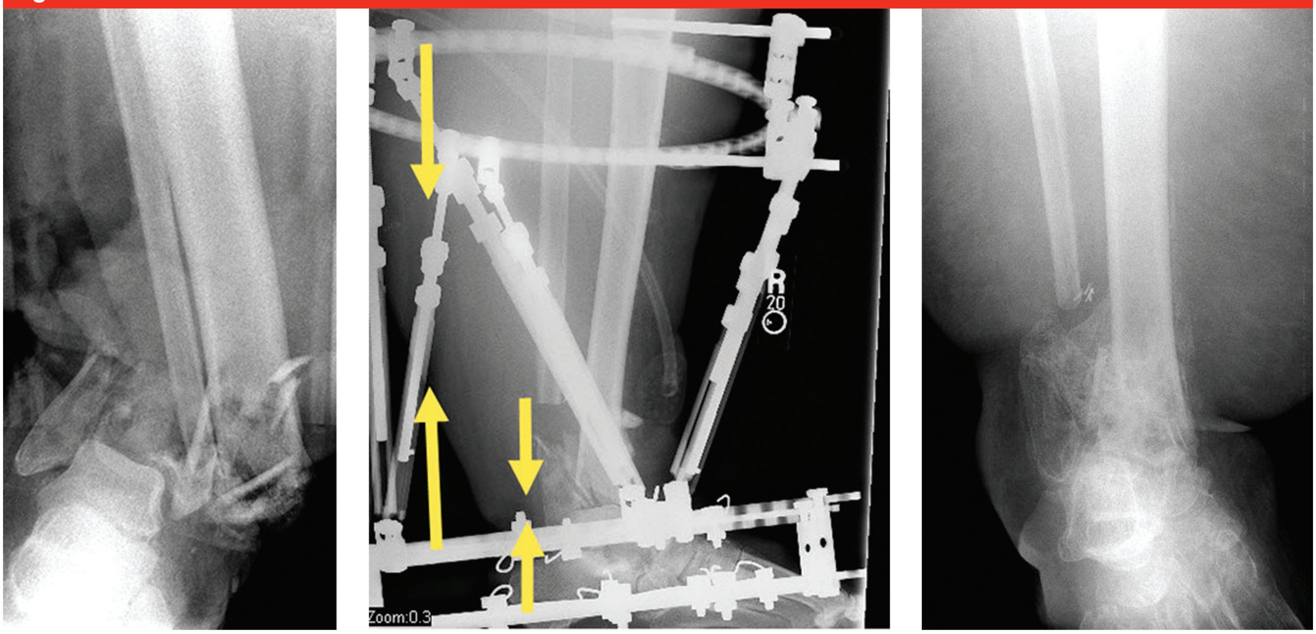
Alternatively, the use of ringed fixators may be considered. Monofocal methods of management involve distal shortening and the acceptance of limited limb length inequality (Figure 8). This step may be done acutely, gradually, or as a combination of both if shortening of >3 cm is necessary. The anticipated limb length inequality associated with acute peripheral shortening may be

Figure 7

A B C

A, AP radiograph of the ankle demonstrating an open pilon fracture in a 72-year-old man. Restoration of the limb length resulted in wound diastasis. He was deemed a poor candidate for soft-tissue coverage. **B**, Clinical photograph of the ankle after deliberate limb shortening was performed, resulting in approximation of robust tissue margins. **C**, AP radiograph of the ankle demonstrating fixation with a posterior plate. Clinical and radiographic union was achieved with restoration of aseptic function.

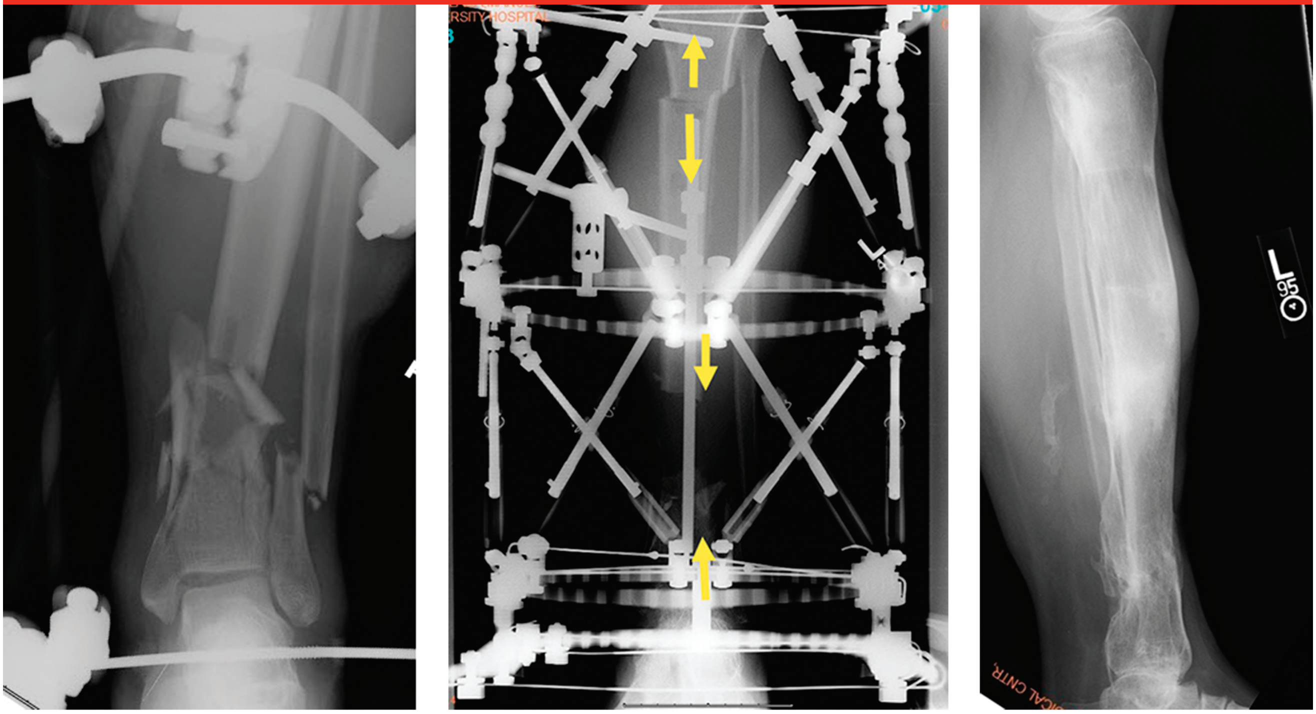
Figure 8



A B C

A, Preoperative AP radiograph of the ankle demonstrating a severe open tibial pilon fracture in a 58-year-old woman who was injured in a motor vehicle collision. Débridement of devitalized tissues resulted in considerable osseous and soft-tissue deficits requiring resection of the distal tibial osteoarticular segment. She was a poor candidate for both soft-tissue reconstruction and osseous regeneration reconstruction maneuvers. **B**, Lateral radiograph of the ankle following monofocal methods of limb shortening with the application of a circular tensioned wire external fixator. This resolved concerns for both soft-tissue and osseous deficits. Acute shortening followed by subsequent gradual shortening was performed to ensure limb perfusion. The arrows to the right indicate intentional acute shortening performed at the time of surgery. The arrows to the left indicate subsequent gradual shortening/compression through the circular frame. **C**, AP radiograph of the ankle obtained 6 months after injury demonstrating successful fusion. (Reproduced with permission from Kottmeier S, Madison R, Divaris N, et al: The infected pilon: Assessment and treatment strategies. *Techniques in Foot & Ankle Surgery* 2016;15:188–196.)

Figure 9



A B C

A, AP radiograph of the ankle showing an open distal tibial pilon fracture with devitalized metadiaphyseal implants in a 42-year-old patient. **B**, AP radiograph of the ankle after application of a circular fixator. A bifocal strategy (two levels of activity) was used with distraction osteogenesis (proximal segment) and intercalary shortening (distal segment). The arrows indicate distraction at the proximal osteotomy site and compression at the distal intercalary defect. **C**, Postoperative lateral radiograph demonstrating satisfactory proximal bone regenerate and union of the distal region of intercalary bones loss. (Reproduced with permission from Kottmeier S, Madison R, Divaris N, et al: The infected pilon: Assessment and treatment strategies. *Techniques in Foot & Ankle Surgery* 2016;15:188–196.)

addressed by distraction osteogenesis techniques within the proximal metaphyseal region of the tibia.[35,36] These techniques can be performed simultaneously (ie, bifocal) or staged at a later date. Bifocal compression/distraction osteogenesis addresses bone loss peripherally (through shortening) and resolves limb length discrepancy by proximal distraction osteogenesis (Figure 9). Limb shortening peripherally, within the region of distal metaphyseal deficit, does not require adjuvant bone grafting techniques or the docking site preparation required with bone transport techniques in which the length of the limb is maintained (ie, a form of monofocal treatment).[37] In contrast to segmental bone transport, acute shortening obviates docking site trajectory concerns. Additionally, adjuvant bone grafting techniques are unlikely to be required; these techniques are frequently required to facilitate docking site union. Several studies have demonstrated the efficacy of described bifocal treatment in the acute management of distal tibial metaphyseal pilon fractures, particularly in the setting of open fractures and metaphyseal deficits.[38,39] The ability to include primary wound closure is unique to acute shortening protocols, thus eliminating the need for complicated soft-tissue reconstruction efforts. This setting is particularly important for patients who cannot undergo complex soft-tissue coverage.

Additional gradual shortening of 2 mm per day has been described for defects >3 cm.[39] Shortening of the distal aspect of the tibia within the region of comminution has been described for defects <3 cm. Caution has been advised when pursuing shortening for defects >3 cm.[40] Deliberate limb length reduction is limited by the circulatory status of the foot, which is monitored by means of intraoperative Doppler ultrasonography of the posterior and anterior tibial arteries. Atbasi et al[41] assessed the arterial configuration after acute tibial shortening with angiographic evaluation. In a clinical study, 16 patients were monitored with intraoperative Doppler and pulse oximetry. The average amount of acute shortening was 5.5 cm (maximum, 8 cm of shortening). Digital subtraction angiography was performed 1 week after the procedure, and CT angiography was performed

2 years after the procedure. No discernible change in the arterial configuration occurred with acute shortening <4 cm; however, increased tortuosity of the vessels was noted. Arterial patency was maintained, and the newly acquired arterial configuration persisted for <2 years with no circulatory or limb perfusion complications. Accordingly, a threshold for immediate acute shortening has yet to be convincingly demonstrated.

Distally, both monofocal and bifocal techniques follow a similar protocol. Devitalized bone margins are resected with aggressive débridement of devitalized structures. Because of the small dimension of the distal fragment and its proximity to the ankle joint, inclusion of the foot within the frame is typically required. This configuration also serves to prevent equinus contracture and offers enhanced stability to the ring construct. With bifocal efforts (acute or staged), a proximal tibial corticotomy is performed in a low-energy fashion by means of multiple drill holes or a Gigli saw. Proximal distraction is initiated at a rate of 1 mm per day, with a latency period of 7 to 10 days. Both unifocal and bifocal treatment methods facilitate closure of the distal traumatic wound. With either method, segmental resection of a portion of the fibula, corresponding to the anticipated measured shortening, is required. This allows approximation of the peripheral proximal and distal fragments. Intentional shortening of the limb may favor primary wound healing and make the soft tissues more resilient to infection and osseous devitalization.

Summary

Recent advances in osteosynthesis of the distal tibial plafond have been promising, offering improved outcomes and fewer complications. The pursuit of anatomic articular reconstitution cannot be at the expense of the soft tissues. Despite adherence to and proper execution of current fixation techniques, infection of the distal tibial pilon after surgical osteosynthesis remains challenging. Patient characteristics, both regional and systemic, must be considered. The limitations and difficulty of these surgical reconstructions must be recognized and accepted by both the treating surgeon and the patient.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 6, 7, 11, 28, and 40 are level III studies. References 1-5, 8-10, 12-17, 20, 21, 23-27, 29-31, 33-35, 37-39, and 41 are level IV studies. References 18, 19, 22, 32, and 36 are level V expert opinion.

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