Current Reviews in Musculoskeletal Medicine (2018) 11:537–545
https://doi.org/10.1007/s12178-018-9519-7

FOOT AND ANKLE TRAUMA (G MOLONEY, SECTION EDITOR)

Evolution in Management of Tibial Pilon Fractures

Jessica Bear[1] · **Natalie Rollick**[1] · **David Helfet**[2]

Published online: 20 October 2018

Abstract

Purpose of Review Tibial plafond, or pilon, fractures can be some of the most difficult fractures to manage. As they are often associated with high-energy trauma, both the soft tissue involvement and the comminuted fracture pattern pose challenges to fixation. Furthermore, the complex anatomy and trauma to the cartilage at the time of injury predispose pilon fractures to poor functional outcomes and high rates of posttraumatic arthritis. This review will discuss the recent developments in the treatment of tibial pilon fractures.

Recent Findings Historically, surgical management of pilon fractures has been associated with high rates of complications, including wound complications, infections, nonunions, and even the need for amputation. In response, staged protocols were created. However, recent studies have called this into question, demonstrating low wound complications with early definitive fixation. Additional studies are evaluating adjuvants to minimize wound complications, including the use of vancomycin powder and oxygen supplementation, while another study challenges the 7-cm myth regarding the distance needed between skin incisions. Additional research has been focused on alternative methods of managing these complex, and sometimes non-reconstructable, injuries with the use of external fixation, minimally invasive internal fixation, and primary arthrodesis.

Summary Tibial pilon fractures remain difficult to treat for even the most skilled orthopedic trauma surgeons. With improvements in surgical techniques and implants, complication rates have declined and outcomes have improved; however, the overall prognosis for these injuries often remains poor.

Keywords Pilon fracture · Plafond fracture · Distal tibia fracture · Intra-articular fracture

Introduction

Tibial pilon fractures are relatively infrequent, accounting for 5–7% of all fractures of tibia [1]. These fractures are caused by axial loading in which the talus is driven into the plafond, resulting in articular impaction of the distal tibia. The position of the foot at the time of impact, in conjunction with the direction and amplitude of the force, results in varying fracture patterns and amount of comminution. Intra-articular distal tibia fractures can also occur from a rotational force with minimal axial load. These fractures are often low energy and therefore cause less insult to the soft tissues and less comminution and should not be considered equal to a true pilon.

Despite the degree of variability seen in high-energy plafond fractures, CT imaging has demonstrated involvement of three relatively consistent main fragments: posterolateral (Volkmann), anterolateral (Chaput), and medial fragments. Theses fragments are associated with soft tissue attachments of the posterior inferior tibiofibular ligament, anterior inferior tibiofibular ligament, and deltoid ligament, respectively.

Traditionally, tibial pilon fractures have been classified according to the AO/OTA and Ruedi-Allgower classification; however, these systems are based on plain radiographs and are not useful tools in terms of preoperative planning or prognostic indicators. Given these limitations, Leonetti and Tigani

This article is part of the Topical Collection on *Foot and Ankle Trauma*

✉ Jessica Bear
bearj@hss.edu

Natalie Rollick
rollickn@hss.edu

David Helfet
helfetd@hss.edu

[1] Orthopedic Trauma Service, Hospital for Special Surgery, Weil Cornell College of Medicine, New York Presbyterian Hospital, 525 East 71st Street, New York, NY 10021, USA

[2] Weill Cornell Medical College, Hospital for Special Surgery, New York, NY 10021, USA

proposed a new classification system based on displacement, the number of articular fragments, the plane of the main fracture line, and the degree of comminution as seen on CT scan. This is the only CT-based classification system described. In an associated study of 71 pilon fractures, they demonstrated that this new classification system is not only reproducible, but provides prognostic correlation [2]. Regardless of which classification system is used, it is important to recognize that there is a high degree of variation between individual fractures. For this reason, a preoperative CT scan is vital in understanding the fracture and planning both surgical approaches and fixation.

Soft Tissue Consideration

Pilon fractures are nearly ubiquitously due to high-energy forces and thus are frequently associated with significant insult to the soft tissues. While lower energy variants exist in elderly patients with osteoporotic bone, the soft tissue injury is often just as severe secondary to age-related tissue fragility. Thorough evaluation of the skin should be done at the time of the initial encounter, assessing for the degree of swelling, presence or absence of skin wrinkles, blistering, and open wounds. While compartment syndrome is not common in these fracture patterns, appropriate examination and consideration should be given, as the sequela of a missed compartment syndrome is devastating.

Early vs Staged Management

Given the unforgiving soft tissue envelope about the distal tibia, it is the state of the soft tissues that dictate the timing of surgery and the degree of surgical insult. Historically, some studies of acute open reduction and internal fixation of pilon fractures demonstrated an unacceptably high rate of infections and wound complications [3, 4]. As a result, staged protocols were introduced, in which fractures were temporized in calcaneal traction, splints, or external fixators until the soft tissue envelope was amenable to surgery. Unfortunately, no definitive clinical signs exist to determine timing for definitive fixation. Surgeons frequently use the presence of wrinkles (Fig. 1) or epithelialization of fracture blisters, but often it is a general "gestalt."

Staged protocols resulted in decreased wound complications; however, they have recently been challenged with a resurgence of early fixation. Concerns regarding quality of reduction, operative time, increased healthcare costs, and pin site infection with the use of external fixators have led a number of surgeons to proceed with definitive internal fixation acutely. Multiple recent studies have shown that fractures treated within 72 h of surgery have comparable outcomes to staged fixation [5••, 6, 7]. However, these studies are all retrospective reviews and criterion for early fixation was surgeon or facility dependent. It is our general practice to determine timing of surgery and need for staging based on the quality of the soft tissue envelope, with the presence of soft tissue wrinkles as our primary determining factor.

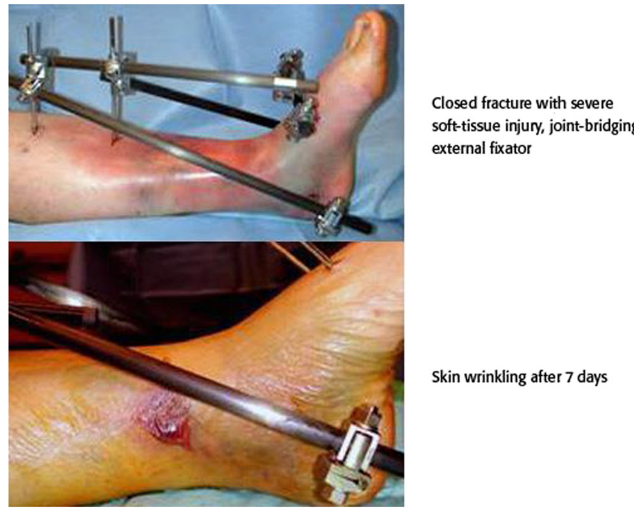


Fig. 1 A closed fracture that was treated in a staged manner with an ankle spanning external fixator. Skin wrinkles returned 7 days post injury (copyright by AO Foundation, Switzerland)

Open Fractures

Open fractures occur commonly and should be managed initially with standard irrigation and debridement methods, as well as early initiation of intravenous antibiotics. Thorough debridement with excision of nonviable bone is vital to creating an environment to promote healing and decrease infection risk. However, effort should be made to maintain bone fragments containing large articular pieces. In high-energy fractures with significant comminution, contamination, and/or periosteal stripping, adequate debridement of nonviable bone may result in significant bone loss; the management of these defects will be discussed later in the article. If the wound can be closed primarily, it is paramount that the skin not be sutured under any tension.

Given the risk of infection, recent studies have evaluated the use of adjuvants in the setting of such open fractures. In a pilot study by O'Toole et al., preoperative supplemental oxygen was used in the setting of open plateau, pilon, and calcaneal fractures. While not statistically significant, they demonstrated a trend towards lower surgical site infections in the group treated with FiO_2 of 80% [8]. A multicenter, randomized control study to further investigate this is currently underway. The same group is also evaluating the use of local vancomycin powder intraoperatively to reduce infections [9].

Open fractures in this area often require soft tissue flap coverage and multiple studies have correlated early flap coverage with lower infection rates. Recently, a study of open tibia fractures demonstrated that time to flap coverage was an independent risk factor for complications, even when controlling for injury severity. While there was no increased risk if coverage was performed within the first 7 days, there was a significant increase in complication rates for each day after seven [10••]. A separate study of Gustilo-Anderson grade III open tibial fractures demonstrates reduced deep infection when soft tissue coverage was performed at the time of definitive fixation compared to staged flap coverage [11]. Based on this, we recommend early and collaborative involvement of plastic surgery colleagues to coordinate fixation and coverage to minimize postoperative complications. When possible, soft tissue coverage should be performed in the same setting as definitive fixation. If single-staged coverage is not feasible, soft tissue coverage should be done as early as possible and should not exceed 7 days.

Approaches

Numerous approaches have been described for the management of pilon fractures. Careful analysis of radiographs and preoperative CT scans are key when deciding which approach(es) to use. CT scans are also extremely helpful in evaluating soft tissue structures that can become entrapped within the fracture, particularly the posteromedial structures, including the posterior tibial neurovascular bundle [12, 13]. Entrapped structures are frequently missed by the radiologist, so scrutiny should specifically address the location of these structures [14].

Approaches include anterolateral, anteromedial, direct anterior, direct lateral, direct medial, posterolateral, and posteromedial [15] (Fig. 2). These approaches all hold their own advantages and disadvantages. The anterior approaches allow direct visualization and reduction of the articular fragments, while posterior approaches rely on indirect reduction of the articular surface by means of fluoroscopic imaging. Incisions can be used alone or in conjunction with one another, but should be determined by the individual fracture pattern for any given patient. We frequently use a lateral approach, with the skin incision placed either along the anterior or posterior border of the fibula [16] (Fig. 2). The former allows for easy access to the anterior and lateral surfaces of the tibia, and specifically the Chaput fragment, while the latter provides access for fibula reduction and fixation. When necessary, we also use an accessory medial approach, which will be discussed later in the article.

Historically, when using dual incisions, surgeons argued for a minimum of a 7-cm skin bridge. This was thought to minimize the risk of soft tissue compromise and wound complications. However, this principle has come under recent scrutiny. Howard et al. demonstrated low soft tissue complications despite 83% of patients having less than 7-cm skin bridges between incisions [17••]. Regardless, it is important to respect the soft tissue envelope with precise handling. Full-thickness skin flaps should be made regardless which incisions are used and a meticulous soft tissue handling technique utilized (Fig. 3), with only gentle retraction on the skin edges to prevent wound necrosis [18].

It is important to recognize that no one approach is right for *all* patients. Surgeons managing these complex fractures should be comfortable with the various approaches to the distal tibia and be prepared to use whichever approach(es) is(are) suitable for the individual soft tissues and fracture configuration.

Goals of Surgical Treatment

In 1979, Rüedi and Allgöwer proposed four sequential principles for the management of fractures of the tibial plafond. These principles include (1) restoration of fibular length, (2) anatomic reduction of the articular surface, (3) filling the residual bone defect with cancellous autograft, and (4) stabilization of the medial column [19]. Conceptually, these principles still hold true, but have evolved overtime.

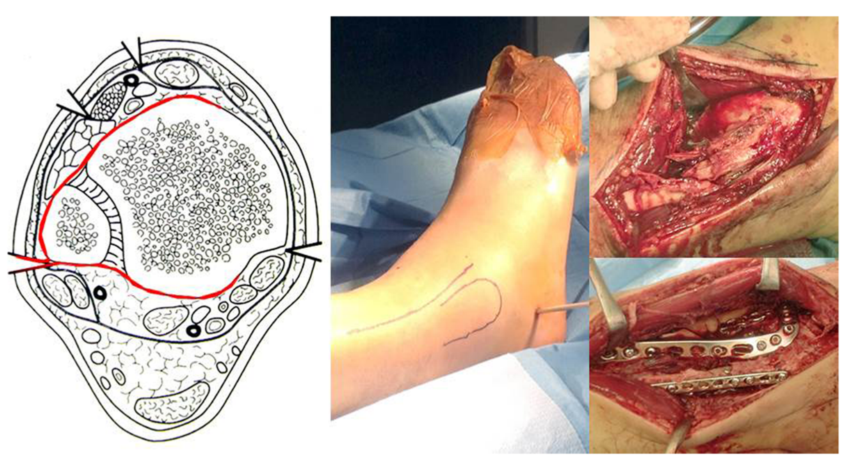


Fig. 2 Various intervals that can be used to approach the distal tibia. The image red line represents our preferred approach when access is needed to both the anterolateral and posterolateral aspects of the tibial plafond. An incision is made along the anterior border of the fibula, and dissection was carried out both anterior and posterior to the fibula, providing access to the fibula and anterolateral tibia

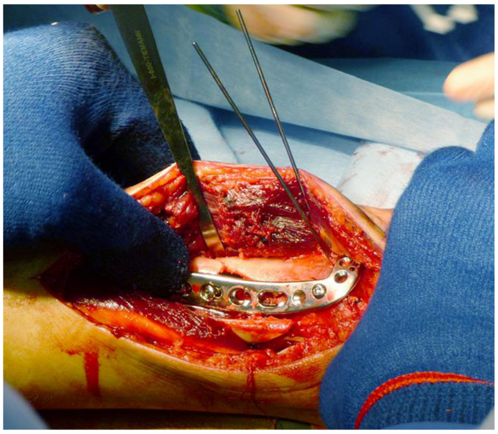


Fig. 3 An anterolateral approach to the distal tibia. Note the full-thickness soft tissue flaps created to access the fracture site. Minimal retraction was used to expose the fracture for plate application. Here, distal K-wires used for temporary stabilization of the articular segments also act as retractors to minimize soft tissue handling

Restoration of Fibular Length

Metaphyseal comminution is frequently present and can make estimation of tibial length difficult. Often the fibula is less comminuted and a more accurate reduction can be obtained. Additionally, stable fixation of the fibula can assist in coronal and translational alignment by providing a lateral buttress. However, recent studies have called into question the need for fibular fixation. In a retrospective review, Kurylo et al. demonstrated no differences in postoperative or final alignment between pilon fractures with and without fibular fixation, arguing that fibula fixation may not be necessary [20]. What is clear is that stabilization of the fibula is imperative in the presence of a syndesmotic injury [21], as its ligamentous attachments are important for syndesmotic stability. We believe the fibula is not only an important stabilizer of the ankle, but also assists in the reduction of the plafond. When adequately reduced and fixed, the fibula acts as a strut and assists in length, alignment, and translation (Fig. 4). If the ligaments of the syndesmosis are intact, namely the anterior inferior tibiofibular ligament and posterior inferior tibiofibular ligament, reduction of the fibula may also assist in the reduction of the Volkmann and Chaput fragments. While this topic is currently being debated in the literature, the authors recommend an anatomic reduction and fixation of the fibula in all pilon fractures when possible.

The timing of fibular fixation, when performed, is a topic of debate. If surgery is to be done in a staged fashion, some argue to reduce and fix the fibula at the time of the placement of the external fixator. This provides increased stability to the frame construct while waiting for the soft tissue envelope to improve, and can decrease operative time at the time of fixation of the plafond. However, it is imperative to obtain an anatomic reduction of the fibula. If not, a malreduction can prevent accurate reduction of the tibia. Additionally, careful consideration is important to ensure that the optimal incision is used to approach the fibula while leaving an adequate skin bridge for additional incisions that may be used. A posterolateral or lateral incision is often used, depending on what access is necessary to address the plafond. It is our recommendation that the fibula should not be stabilized until the time of definitive fixation of the pilon.

Anatomic Reduction of the Articular Surface

AO principles dictate anatomic reduction and absolute stability of the articular surface for any intra-articular fracture. It is believed that restoration of the articular surface decreases the risk of posttraumatic arthritis, ultimately leading to improved outcomes. However, while the quality of articular reduction has been shown to affect radiographic arthrosis, studies have been unable to demonstrate a link between quality of articular reduction and outcomes [22]. While a more recent prospective study by Sommer et al. demonstrated a link between restorations of fibular length with functional outcomes, there was no correlation found between articular step off and articular gap [23]. However, the mean step off in this series was 0.03 mm and mean gap 0.13 mm, which may represent good to excellent articular reductions in the majority of patients. It remains our belief that the articular reduction is still a valuable piece of the puzzle, and we *must* continue to strive for an anatomic reduction whenever feasible.

Filling of Metaphyseal Bone Defect

Given the high energy associated with the injuries, and significant impaction that often accompanies them, there is frequently a bone deficit following reduction of the articular segment. To support the articular segment and prevent subsidence, various filling agents have been used, including autologous bone graft, cancellous and structural allograft, calcium-based cements, and demineralized bone matrix products. While each comes with its inherent pros and cons, there is no evidence that demonstrates a clear advantage of any one graft material over the other. It is our preference to use a structural wedge demineralized bone matrix product that is osteoinductive and provides structural support. If an intramedullary strut is necessary for reduction and stabilization, then a fibula allograft is our graft of choice.

Fixation of the Medial Column

The original study by Ruedi and Allgower argued for independent fixation of the medial column with a buttress plate as the mainstay of fixation. In more recent years, many surgeons have moved away from this principle in lieu of anterolateral locking plates. However, a recent study involving three such

Fig. 4 Radiographs and CT scan demonstrate a partial articular pilon fracture. Dual incisions with anterolateral and medial approaches were used to build back to an intact posterior column

plates, which are commercially available, showed that the distal screw configuration frequently misses, or inadequately captures, the major medial fragment [24•]. We recommend careful scrutiny of the preoperative CT to determine the likelihood that anterolateral plate fixation will provide adequate fixation of the medial segment, and consideration for additional medial fixation, either with a low profile plate or medial column screw(s). We often find it useful to place a medial plate subcutaneously through minimally invasive incisions to buttress and correct any varus deformity [16] (Fig. 5). We frequently use small fragment plates with cortical screws.

Surgical Fixation

External Fixation

External fixation can be used as a temporary measure to stage tibial pilon fractures, as well as for definitive fixation. It relies on the principle of capsuloligamentotaxis to indirectly reduce the fracture by tensioning the soft tissues about the ankle. When used in a temporary manner for staging purposes, careful placement of pins out of the zone of injury and planned surgical bed is important to reduce infection risks, as increased infections rates have been reported when definitive internal fixation spanned the site of provisional external fixator pin sites [25].

Open Reduction and Internal Fixation

The mainstay of treatment today is still open reduction and internal fixation for the vast majority of pilon fractures. This provides direct visualization of the articular reduction and allows for direct reduction of metadiaphyseal segment. Adequate reduction and fixation begins with careful evaluation of the preoperative CT scan to determine optimal approach(es) and hardware positioning. Although commonalities are shared, each fracture should be approached as an individual entity and operative plan tailored to the nuances of any particular fracture.

If the fracture of the tibia and fibula are to be addressed in the same setting, the order of stabilization is dependent on the fracture pattern. Stabilization of a simple fracture of the fibula in which anatomic reduction can confidently be obtained may be done first in order to assist the reduction and alignment of the tibia. However, it may be beneficial to address the tibia first in the setting of a highly comminuted fibula fracture, or a more distally based fibula fracture. In distal fibula fractures, it is sometimes possible to access the plafond through the fibula fracture.

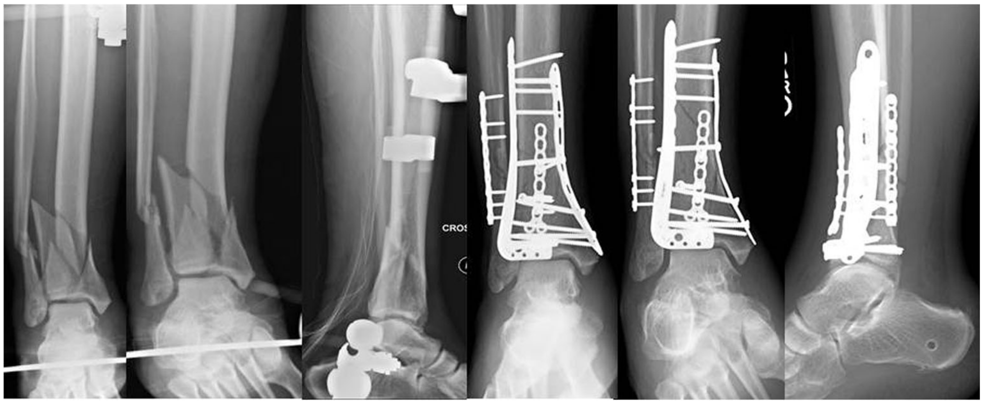


Fig. 5 A complete articular tibial plafond fracture managed using staged protocol with an ankle spanning external fixator to temporize the soft tissues. The fracture was subsequently stabilized with an anterolateral distal tibia locking plate and supplemental fixation of the metaphyseal fragment. Additionally, a subcutaneous low-profile medial anti-glide plate was utilized to support the medial column that was not captured by the anterolateral plate

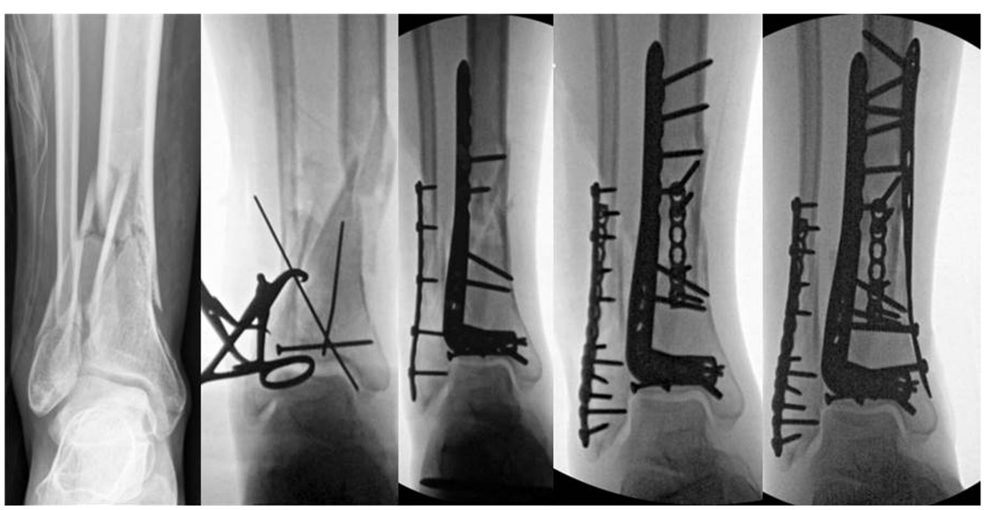
Reduction of the tibia should begin with the articular surface. In partial articular patterns, we recommend to build to the stable column. In complete articular patterns, we find it best to reconstruct the articular segment, then affix this segment to the metadiaphysis, i.e., "turning a C type into an A type" (Fig. 6). More times than not, reconstruction of the articular segment should be done from posterior to anterior. Distraction of the tibiotalar joint with an external fixator or femoral distractor, with a pin in the calcaneus or talus, is helpful to increase visualization of the joint surface. After reduction is obtained of the articular segment, compression along the joint surface and fixation with absolute stability principles should be utilized.

When addressing the metaphyseal segment, absolute stability with lag screws should be used in the setting of simple fracture patterns. In contrast, comminuted fracture patterns should be stabilized with bridging constructs to obtain relative stability. Precontoured locking and nonlocking plates are commercially available for the distal tibia. Relative indications for the use of locking plates include osteoporotic bone and short metaphyseal segments; however, it is important to note that there is no data demonstrating superior outcomes with the use of locking plates. As noted earlier, these precontoured plates often do not adequately capture all fracture fragments. Supplemental fixation with additional plates may be necessary, particularly along the medial column or in large posterolateral fragments with a shear-type pattern. Low profile plates should be considered for use as they have less wound complication and are less symptomatic [26].

Minimally Invasive Plate Osteosynthesis (MIPO) /Intramedullary Nailing (IMN)

Given the poor soft tissue envelope, soft tissue sparing approaches have been developed. MIPO techniques, using a medial plate, and/or intramedullary tibial nailing have been described for use in extra-articular and simple intra-articular fractures. It is believed that these methods minimize soft tissue

Fig. 6 The sequence of reduction and fixation for a C-type pilon fracture, from left to right. First, the articular surface was reduced and provisionally stabilized with K-wires and an independent lag screw. Length and alignment were then re-established by reduction of the lateral column. This was accomplished with reduction and stabilization of the fibula, as well as the lateral plafond. Lastly, the medial column was restored and buttressed using a low-profile scallop plate



stripping and, given smaller incisions, can be used in patients with soft tissue compromise. In both techniques, the articular surface, if involved, should first be reduced, compressed, and stabilized. While good functional outcomes and high union rates have been reported, malunions have also been noted. In one study, valgus malalignment was seen with the use of intramedullary nails in 2.7% of patients, and recurvatum of > 10° reported in 27.8% of patients treated with MIPO [27•]. A separate study of use of the MIPO technique demonstrated an overall complication rate of 23.8%, notable for delayed union and soft tissue impingement [28]. Given these risks, we would advise careful scrutiny of intraoperative imaging to prevent malreduction and malunion, as well as sufficient compression across the articular surface to result in absolute stability at that level.

Definitive External Fixation

Circular frame fixators have been used as definitive fixation for high-energy pilon fractures in which the bone or soft tissue injury precluded internal fixation. Thin wire frames and hybrid fixators have been described with high union rates [29, 30]. Although there are also high rates of pin tract infections, deep infections and osteomyelitis are rare. As the articular surface is often highly comminuted with no soft tissue attachments, capsuloligamentotaxis cannot reliably reduce the articular fragments, particularly in the setting of impaction or central depression. Limited internal fixation has been used in addition to frame constructs to improve the quality of the reduction. A meta-analysis comparing this method with open reduction and internal fixation found no difference in infection or complication rates between the two groups [31]. Additionally, no difference in functional outcomes has been found between articulating external fixators that allow early ankle motion and those that immobilize the ankle for a prolonged period of time [32].

Primary Arthrodesis

Recently, attention has been on the use of primary arthrodesis for the management of severely comminuted plafond fractures. Although there are no definitive indications for primary arthrodesis, it has been used in cases in which reconstruction of the articular surface is not feasible, either due to the amount of comminution, delamination of the articular cartilage, or in elderly patients who are poor candidates for multiple surgical procedures with prolonged weight-bearing restrictions. In these situations, long-term outcomes are dismal, with early onset of posttraumatic arthritis, chronic pain, and poor function. It is theorized that primary fusion of the tibiotalar joint can speed up the recovery process and decrease pain in the long term.

Various methods have been described to obtain fusion, including anterior plating, posterior blade plates, intramedullary hindfoot nails, and use of external fixation, as well as a combination of internal and external fixation. Recent studies have shown good outcomes with high union rates (of both the fracture and fusion site) and good functional outcomes [33, 34, 35•, 36]. However, ankle arthrodesis does increase the risk of adjacent joint arthritis, particularly involving the subtalar joint and midfoot [37]. Given these risks, it is our opinion that primary arthrodesis should be considered on a case-by-case manner and used only in patients in which reconstruction of the articular surface is not a viable option.

Management of Bone Defect

Metaphyseal bone loss can result from impaction at the time of injury often complicated by severe osteoporosis. The resulting defect should be filled in order to aid bony healing and prevent loss of reduction through support of the articular surface. Various agents have been used for smaller defects (< 5 cm), including autologous bone graft, structural (fibular strut graft) or cancellous allograft, demineralized bone matrix, and synthetic substitutes (calcium phosphate and calcium sulfate).

In the setting of an open injury, debridement of nonviable bone may result in a significant bone defect that is not amenable to the above listed filling agents. In such cases, more complex treatment options are available for limb salvage, including induced membrane technique (Masquelet technique), acute shortening with distraction osteogenesis, bone transport, and vascularized bone graft. Composite osteocutaneous grafts, such as vascularized fibula with a cutaneous paddle, are especially useful in the setting concomitant soft tissue defects. While various case series have been published demonstrating efficacy of the various methods, to our knowledge, there have been no comparison trials performed to demonstrate a superiority of any particular method [38].

Conclusion

Tibial pilon fractures are complex injuries that are difficult to treat for even the most skilled orthopedic trauma surgeons. The combination of articular cartilage injury, metaphyseal comminution, and soft tissue insult has often resulted in historically poor outcomes. Respect for the soft tissue envelope is the first step in minimizing complications. While open reduction and internal fixation remains the mainstay for treatment of the majority of these fractures, additional treatment modalities, such as external fixation and primary arthrodesis, are emerging and should be considered for more complex cases. Although advances in surgical techniques and implants have led to improved outcomes over time, the overall prognosis for these injuries often remains poor. Additional research and innovation is needed to continue to improve results and the quality of life of patients affected by pilon fractures.

Compliance with Ethical Standards

Conflict of Interest All authors declare no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance

1. Mauffrey C, Vasario G, Battiston B, Lewis C, Beazley J, Seligson D. Tibial pilon fractures: a review of incidence, diagnosis, treatment, and complications. Acta Orthop Belg. 2011;77(4):432–40.
2. Leonetti D, Tigani D. Pilon fractures: a new classification system based on CT-scan. Injury. 2017;48(10):2311–7.
3. Wyrsch B, McFerran MA, McAndrew M, et al. Operative treatment of fractures of the tibial plafond. A randomized, prospective study. J Bone Joint Surg Am. 1996;78(11):1646–57.
4. Dillin L, Slabaugh P. Delayed wound healing, infection, and nonunion following open reduction and internal fixation of tibial plafond fractures. J Trauma. 1986;26(12):1116–9.
5.•• White TO, Guy P, Cooke CJ, et al. The results of early primary open reduction and internal fixation for treatment of OTA 43.C-type tibial pilon fractures: a cohort study. *J Orthop Trauma*. 2010;24(12):757–63. **A study of 95 patients underwent early definitive fixation of AO/OTA type 43C pilon fractures. Ninety-eight percent of patients were treated within 48 h of presentation. Wound complications were noted in 19% of open fractures and 2.7% of closed fractures.**
6. Tang X, Liu L, Tu CQ, Li J, Li Q, Pei FX. Comparison of early and delayed open reduction and internal fixation for treating closed tibial pilon fractures. Foot Ankle Int. 2014;35(7):657–64.
7. Liporace FA, Yoon RS. Decisions and staging leading to definitive open management of pilon fractures: where have we come from and where are we now? J Orthop Trauma. 2012;26(8):488–98.
8. RV OT, Joshi M, Carlini AR, et al. Supplemental perioperative oxygen to reduce surgical site infection after high-energy fracture surgery (OXYGEN study). J Orthop Trauma. 2017;31(Suppl 1):S25–31.
9. O Toole RV, Joshi M, Carlini AR, et al. Local antibiotic therapy to reduce infection after operative treatment of fractures at high risk of infection: a multicenter, randomized, controlled trial (VANCO study). J Orthop Trauma 2017;31 Suppl 1:S18-S24.
10.•• D'Alleyrand JC, Manson TT, Dancy L, et al. Is time to flap coverage of open tibial fractures an independent predictor of flap-related complications? *J Orthop Trauma*. 2014;28(5):288–93. **This retrospective review evaluated 69 open tibia fractures that required flap coverage. The authors found that time to flap coverage was an independent risk factor for complications, even when controlling for injury severity. They also found that the odds of complication increased by 11% for each day beyond day 7.**
11. Mathews JA, Ward J, Chapman TW, Khan UM, Kelly MB. Single-stage orthoplastic reconstruction of Gustilo-Anderson grade III open tibial fractures greatly reduces infection rates. Injury. 2015;46(11):2263–6.
12. Tresley J, Subhawong TK, Singer AD, Clifford PD. Incidence of tendon entrapment and dislocation with calcaneus and pilon fractures on CT examination. Skelet Radiol. 2016;45(7):977–88.
13. Fokin A, Huntley SR, Summers SH, et al. Computed tomography assessment of peroneal tendon displacement and posteromedial structure entrapment in pilon fractures. J Orthop Trauma. 2016;30(11):627–33.
14. Eastman JG, Firoozabadi R, Benirschke SK, Barei DP, Dunbar RP. Entrapped posteromedial structures in pilon fractures. J Orthop Trauma. 2014;28(9):528–33.
15. Crist BD, Khazzam M, Murtha YM, Della Rocca GJ. Pilon fractures: advances in surgical management. J Am Acad Orthop Surg. 2011;19(10):612–22.
16. Grose A, Gardner MJ, Hettrich C, Fishman F, Lorich DG, Asprinio DE, et al. Open reduction and internal fixation of tibial pilon fractures using a lateral approach. J Orthop Trauma. 2007;21(8):530–7.
17.•• Howard JL, Agel J, Barei DP, Benirschke SK, Nork SE. A prospective study evaluating incision placement and wound healing for tibial plafond fractures. *J Orthop Trauma*. 2008;22(5):299–305. **discussion 305–296. This prospective study evaluated 46 tibial pilon fractures for wound complications in the setting of multiple incisions. Wound complications were noted in 9% of patients; however, 83% of patients had skin bridges less than 7 cm between incisions.**
18. Thordarson DB. Complications after treatment of tibial pilon fractures: prevention and management strategies. J Am Acad Orthop Surg. 2000;8(4):253–65.
19. Rüedi TP, Allgöwer M. The operative treatment of intra-articular fractures of the lower end of the tibia. Clin Orthop Relat Res. 1979;138:105–10.
20. Kurylo JC, Datta N, Iskander KN, Tornetta P. Does the fibula need to be fixed in complex pilon fractures? J Orthop Trauma. 2015;29(9):424–7.
21. Torino D, Mehta S. Fibular fixation in distal tibia fractures: reduction aid or nonunion generator? J Orthop Trauma. 2016;30(Suppl 4):S22–5.
22. Williams TM, Nepola JV, DeCoster TA, Hurwitz SR, Dirschl DR, Marsh JL. Factors affecting outcome in tibial plafond fractures. Clin Orthop Relat Res. 2004;423:93–8.
23. Sommer C, Nork SE, Graves M, Blauth M, Rudin M, Stoffel K. Quality of fracture reduction assessed by radiological parameters and its influence on functional results in patients with pilon fractures—a prospective multicentre study. Injury. 2017;48(12):2853–63.
24.• Aneja A, Luo TD, Liu B, et al. Anterolateral distal tibia locking plate osteosynthesis and their ability to capture OTAC3 pilon fragments. *Injury.* 2017. **A compilation of digitized fracture lines for 169 pilon fractures; fracture lines were graphically superimposed. By comparing theses maps to sawbone models following application of three commercially available distal tibia locking plates, the authors found that the distal screw configuration frequently misses, or inadequately captures, the major medial fragment.**
25. Shah CM, Babb PE, McAndrew CM, et al. Definitive plates overlapping provisional external fixator pin sites: is the infection risk increased? J Orthop Trauma. 2014;28(9):518–22.
26. Borens O, Kloen P, Richmond J, Roederer G, Levine DS, Helfet DL. Minimally invasive treatment of pilon fractures with a low profile plate: preliminary results in 17 cases. Arch Orthop Trauma Surg. 2009;129(5):649–59.
27.• Beytemür O, Barış A, Albay C, Yüksel S, Çağlar S, Alagöz E. Comparison of intramedullary nailing and minimal invasive plate osteosynthesis in the treatment of simple intra-articular fractures of

the distal tibia (AO-OTA type 43 C1-C2). *Acta Orthop Traumatol Turc*. 2017;51(1):12–6. **In a retrospective comparison of patients with simple intra-articular distal tibia fracture patterns treated with intramedullary nails vs MIPO fixation, authors found high rates of malalignment. More frequent coronal deformity was seen with IMN, and recurvatum was found in 27.8% of patients treated with MIPO.**

28. Vidović D, Matejčić A, Ivica M, Jurišić D, Elabjer E, Bakota B. Minimally-invasive plate osteosynthesis in distal tibial fractures: results and complications. Injury. 2015;46(Suppl 6):S96–9.
29. Galante VN, Vicenti G, Corina G, Mori C, Abate A, Picca G, et al. Hybrid external fixation in the treatment of tibial pilon fractures: a retrospective analysis of 162 fractures. Injury. 2016;47(Suppl 4): S131–7.
30. Kapoor SK, Kataria H, Patra SR, Boruah T. Capsuloligamentotaxis and definitive fixation by an ankle-spanning Ilizarov fixator in high-energy pilon fractures. J Bone Joint Surg Br. 2010;92(8):1100–6.
31. Zhang SB, Zhang YB, Wang SH, Zhang H, Liu P, Zhang W, et al. Clinical efficacy and safety of limited internal fixation combined with external fixation for pilon fracture: a systematic review and meta-analysis. Chin J Traumatol. 2017;20(2):94–8.
32. Marsh JL, Muehling V, Dirschl D, Hurwitz S, Brown TD, Nepola J. Tibial plafond fractures treated by articulated external fixation: a randomized trial of postoperative motion versus nonmotion. J Orthop Trauma. 2006;20(8):536–41.
33. Abebe E, Farrell DJ, Zelle B, Gruen G. Primary posterior blade plate tibiotalar arthrodesis: a salvage procedure for complex nonreconstructable pilon fractures. J Orthop Trauma. 2017;31(Suppl 3):S30–3.
34. Beaman DN, Gellman R. Fracture reduction and primary ankle arthrodesis: a reliable approach for severely comminuted tibial pilon fracture. Clin Orthop Relat Res. 2014;472(12): 3823–34.
35.• Zelle BA, Gruen GS, McMillen RL, Dahl JD. Primary arthrodesis of the tibiotalar joint in severely comminuted high-energy pilon fractures. *J Bone Joint Surg Am*. 2014;96(11):e91. **In a retrospective review of 20 patients treated with primary tibiotalar arthrodesis, authors identified no wound complications or dehiscence. In addition, all patients were independent ambulators at the time of final follow-up and were found to have SF-36 scores similar to those historically reported for ORIF.**
36. Ho B, Ketz J. Primary arthrodesis for tibial pilon fractures. Foot Ankle Clin. 2017;22(1):147–61.
37. Ling JS, Smyth NA, Fraser EJ, Hogan MCV, Seaworth CM, Ross KA, et al. Investigating the relationship between ankle arthrodesis and adjacent-joint arthritis in the hindfoot: a systematic review. J Bone Joint Surg Am. 2015;97(6):513–20.
38. Chimutengwende-Gordon M, Mbogo A, Khan W, Wilkes R. Limb reconstruction after traumatic bone loss. Injury. 2017;48(2):206–13.