DOI: https://doi.org/10.30795/jfootankle.2024.v18.1857

Special Article

Pilon Fractures: Update on treatment

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Abstract

Tibial pilon fractures (plafond) are severe injuries resulting from predominately axial impaction. They are typically accompanied by severe damage to the vulnerable soft tissue envelope and the articular damage, making these fractures prone to complications. Treatment is individualized to the three-dimensional pathoanatomy, soft tissue damage, functional demands, compliance, and comorbidities of the affected patient. Most pilon fractures will benefit from stage management, which consists of primary closed reduction via ligamentotaxis, external fixation, and secondary internal fixation after soft tissue consolidation. In the hands of an experienced team with all resources available, primary definite internal fixation seems to be associated with similar results and complication rates but faster rehabilitation. Primary fixation of the fibula is rarely helpful, and definite fixation is not necessary in every case. The choice of approaches is guided by the individual fracture pattern, which ensures minimal soft tissue and periosteal dissection. Minimally invasive techniques should be employed whenever feasible. The goals of pilon fracture treatment are anatomic reconstruction of the joint surface and stable axial realignment towards the tibial shaft, bridging any metaphyseal comminution with the least possible amount of soft tissue and periosteal stripping. The choice of implants, particularly the number of plates, should be balanced between absolute stability on one side and preservation of the blood supply to the bone and soft tissues and the chance of callus formation for faster bone healing on the other.

Level of evidence V; Experience-Based Expert Opinion.

Keywords: External fixators; Minimally Invasive Surgical Procedures.

Introduction

There are various definitions concerning the concept of “pilon fracture” (pilon = French for “pestle”); however, there is a general agreement that the correct definition is a distal tibial fracture that involves the weight-bearing zone of the ankle joint surface (plafond = French for “roof”), extending into the tibial metaphysis[(1-6)]. Both terms-pilon and plafond-are used interchangeably in the literature. Pilon fractures represent 1% of lower limb fractures and must be understood as a wide array of osteoarticular, metaphyseal, and soft tissue injuries; this is why managing this fracture remains a challenging and complex issue for clinicians[(7)]. In general, these are high-energy injuries that occur in young patients, and the typical mechanism involves axial compression combined with shearing forces. The classical fragment pattern that develops after the talus impacts the distal tibial and the location and extent of articular comminution are determined by foot position[(7-9)]. Unfortunately, the prognosis of this injury is not encouraging, often resulting in life-altering disability and reduced quality of life[(10)].

As with any intraarticular fracture, the goal of operative treatment of pilon fractures is to achieve an anatomical reduction of the joint surface and axial alignment. However, this task is challenging due to the frequent encounters of significant comminution. Even with direct visualization or conventional fluoroscopy, non-anatomical reduction may occur, negatively affecting outcomes[(10)]. In a study by Vetter et al.[(11)], 43 out of 143 patients (30%) underwent correction

Study performed at the Clinica Guadalupe, San Juan, Argentina.

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How to cite his article: Mombello F, Vera G, Rammelt S. Pilon Fractures: Update on treatment. J Foot Ankle. 2024;18(3):274-91.

after an intraoperative computed tomography (CT) scan due to inadequate joint line reduction[11]. Nevertheless, adequate reduction has not always translated into good functional outcomes, which can be explained by the damage to bone, cartilage, and soft tissues caused by the initial trauma[12,13].

Classification

Rüedi and Allgöwer[14] described the first radiographic pilon fracture classification[14]. These authors classified them increasingly according to severity; however, only poor agreement and reliability have been reported[15,16].

The Arbeitsgemeinschaft für Osteosynthesefragen (AO) introduced a widely used classification system with higher reliability and moderate agreement between observers. It has also been adopted by the Orthopaedic Trauma Association (OTA), and the distal tibial segment is collectively assigned the number 43. Fractures are divided according to the AO system into types A (extraarticular), B (partial articular), and C (complete articular). Further subclassification describes the amount of fragmentation[17,18]. It is easy to use and has a good prognostic value, but when used alone, it does not provide enough information on the morphology of the fracture for precise preoperative planning[19-21].

Urs Heim identified up to six main articular fragments regularly seen on CT scanning in AO type C pilon fractures, which are most useful for preoperative planning[22] (Figure 1). Leonetti and Tigani described a CT-based classification as reliable and reproducible, with high inter and intraobserver agreement. Each degree of severity in their classification correlates inversely with the American Orthopaedic Foot & Ankle Society (AOFAS) score[23]. This classification is based on joint involvement, displacement, number of fragments, the reference fracture lines, and the areas of comminution ranging from type 1 (a nondisplaced fracture) to type 4 (more than four fragments and significant comminution)[23].

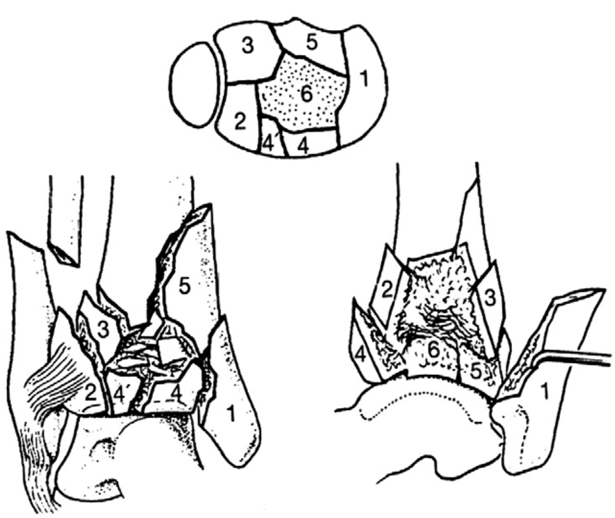

Figure 1. The main fragments of a comminuted C3 pilon fracture that can be regularly identified are, according to Heim [H]: 1 medial malleolus; 2 anterolateral (Chaput); 3 posterolateral (Volkmann); 4 anterior; 5 posterior; 6 central impacted (die punch) fragment(s).

Cole et al.[24], when analyzing the course of intraarticular fracture lines in axial CT scans ("pilon map"), described a constant Y-shaped fracture configuration in the AO/OTA 43C3 with a base of the Y at the fibular notch[24]. These authors identified three main fracture fragments, anterolateral, posterolateral, and medial, with the comminution area located centrally or in the anterolateral quarter of the plafond[24]. Similarly, Korrapati et al.[25] identified three typical fragments, anterior, posterior, and medial, with the "Y" shape being the most frequent configuration[25]. Additionally, they found that the central area is the most common depression site[25]. Assal et al.[26] developed a three-column model of medial, lateral, and posterior tibial pilon fractures, which find their expression at the joint level in the above-described three main fragments[26]. Chen et al.[27] later developed this into a four-column theory by including the fibula as a lateral column[27]. The involvement of each column is related to the foot position at the time of the initial trauma. It has to be noted, however, that none of these models consider the frequently encountered central impacted ("die punch") fragments essential for reconstructing the articular surface.

In AO/OTA type B fractures, the distinction between posterior pilon and posterior malleolar fractures with joint impaction is merely a matter of convention[28]. In posterior pilon fracture, the transverse fracture line runs anterior to the intermalleolar line, and the medial malleolus is fractured as a whole. In contrast, in posterior malleolar fractures, the fracture line runs posterior to the intermalleolar line and into the intercollicular groove of the medial malleolus in Bartoníček-Rammelt type 3 fractures or behind the posterior colliculus in Bartoníček-Rammelt type 4 fractures[29]. Rammelt et al.[30] also described a fracture at the anterolateral distal tibia (tubercule the Chaput, anterior malleolus type 3) with joint impaction[30]. In analogy to the posterior pilon fracture, an anterior pilon fracture would run posterior to the intermalleolar line and/or extend medially into the medial malleolus[31]. It has to be noted that there is a "grey zone" between those entities because both anterior and posterior malleolar fractures are frequently the result of combined rotational and axial impaction forces producing these "pilon variant" fractures[30,32].

Initial management

In most cases, the standard of care for this complex injury with critical soft tissue conditions consists of a two-stage approach, with temporary external fixation for damage control and an open reduction and internal fixation (ORIF). This method has significantly reduced the incidence of soft tissue complications and infections compared to earlier studies with early total care for all patients[33,34]. The objectives are early closed reduction, restoring the length, rotation, and alignment of the limb while providing an optimal environment for soft tissue recovery[12,35,36]. During the initial management, we do not recommend performing definitive treatment on the fibula because malreduction could jeopardize the overall fixation strategy and require revisions during definitive treatment.

After confirmation of the diagnosis by plain radiographs (Figure 2), the sequential management of this injury should be "span, scan, and plan" with meticulous soft tissue care[37] :

1. Span: Joint spanning external fixation, for instance, using a delta frame construct with two parallel pins in the tibial shaft (Figure 3). The superior Schanz screw should be placed a few centimeters distal to the tibial tubercle avoiding the metadiaphyseal extent of the fracture, another Schanz screw into the posterior tuberosity of the calcaneus (alternatively into the talar neck), and the last one in the first metatarsal base or the medial cuneiform to avoid equinus[38]. This construct has demonstrated the lowest relative micromovement during simulated gait in a biomechanical study[39].
2. Scan: A CT scan, including three-dimensional (3D) reconstructions, is essential to gain adequate insight into fracture patterns, allowing optimal surgical planning[40] (Figure 4). Tornetta et al.[41] reported that, after evaluating the CT scans, 64% of surgical plans had changed in their patient cohort[41]. Keiler et al.[42] identified that CT scanning should include 3D reconstruction, as it has shown greater inter and intraobserver reliability regarding the Rüedi-Allgöwer and AO/OTA classifications and a greater agreement for surgical planning between observers when compared to two-dimensional multiplanar CT[42]. We also recommend postoperative CT scanning to accurately evaluate the quality of reduction and the eventual need for early revision.
3. Plan definitive fixation: The choice of approaches, sequence of reduction, and fixation is planned with 3D analysis of the CT scans after closed reduction and external fixation. The soft tissue conditions dictate the timing of definitive fixation. Blisters, as reported in up to 25% of cases, may lead to changes in surgical planning, delays in definitive fixation, and infection[43]. Blisters indicate the energy of the trauma, as an association has been reported with AO type 43C fractures[25]. These cases have been reported to take 14 days to provide an optimal environment before definitive surgery, compared to 7.9 days for patients who did not have blisters[25]. In open fractures, negative pressure wound therapy is highly encouraged to create a more favorable environment for definitive fixation[44]. Multiple authors have reported two safe time frames for definitive

Figure 2. Anteroposterior and lateral radiographs of a 51-year-old male patient who suffered a motocross injury showing a type C pilon fracture with obvious metaphyseal and intraarticular comminution and a two-level fibular fracture.

Figure 3. External fixation with the delta frame configuration.

fixation: within the first six hours post-injury and between six to 12 days post-injury[45,46]. However, complications during both periods have also been reported[45,46]. Skin wrinkling signs reliably indicate edema subsidence and timing for definitive surgery[44].

Approaches

The approaches should be defined according to the fracture pattern, the reference fragment, and the location of the greatest displacement. The principal approaches described in the literature are:

1. Direct anterior (midline): This approach allows complete visualization of the distal tibia and versatile hardware positioning[47]. It is centered over the ankle and slightly curved, distally towards the talonavicular joint. After the skin incision, care is taken to spare the superficial peroneal nerve that crosses the wound from the lateral side distally[48]. Then, the extensor retinaculum is incised, and the anterior tibial tendon is retracted medially, while the extensor hallucis longus tendon with the deep neurovascular bundle is retracted laterally. Proximally, the approach can be extended following the lateral border of the tibial crest[48].
2. Anterolateral (Böhler's approach): This approach is preferred for C3-type injuries with a small or comminuted Chaput fragment. The patient is placed in the supine position, and the approach is made between the tibia and fibula, extending distally for approximately 4 cm while taking care to identify the lateral branch of the superficial peroneal nerve. The structures of the anterior compartment and the neurovascular bundle are retracted medially with the extensor tendons, and a lateral arthrotomy is performed[49]. The reported complications include injury to the peroneal nerves and anterior tibial neurovascular bundle, while it reportedly has the lowest amputation rate and a higher rate of radiographic consolidation compared to the anteromedial approach[50,51].
3. Anteromedial: This approach begins 4 cm proximal to the tibiotalar joint, medial to the tibial crest, and can be extended distally in the same manner as the direct anterior approach. It allows only poor visualization of the Tillaux-Chaput fragment and is associated with high complication rates compared to the anterolateral approach, particularly a significant increase in deep, superficial infections and nonunion[52,53]. The anteromedial approach may be modified, starting 10 mm distal to the medial malleolus and extending proximally, crossing obliquely to the lateral border of the tibia. It then curves to 105º-100° proximally, 10 mm lateral to the tibial crest[46].
4. Lateral: A standard lateral approach will fix an associated distal fibular fracture if not fixed through a posterolateral

Figure 4. (A) Axial, (B) coronal, and (C) sagittal computed tomography scans show the main intraarticular fragments: 1 medial malleolus; 2 anterolateral; 3 posterolateral; 4 anterior; 5 posterior; and 6 a slightly impacted central impacted fragment. Not the irregular bone structure after a distal tibial shaft fracture 20 years ago (same patient as in Figure 2).

approach. This approach has a low risk of complications; however, care must be taken to avoid injury to the lateral branch of the superficial peroneal nerve at its proximal end. The exact position of the incision depends on the location of the fibular fracture and the approach(es) to the distal tibia.

5. Posterolateral: It is performed with the patient in the prone position, midway between the Achilles tendon and the fibula. The sural nerve that runs epifascially from central to lateral is identified in the subcutaneous tissue and gently mobilized medially with the lesser saphenous vein(54). Then, superficial and deep crural fascia are incised, and the posterior tibia and fibula are accessed in the interval between the flexor hallucis longus and peroneal muscles, which can be retracted medially and laterally, respectively(48). This approach is particularly useful as it allows for treating posterior pilon fractures associated with fibular fractures(29,55). With careful soft tissue management, the reported wound complication rates and sural nerve injuries are low in the treatment of posterior pilon fractures due to the extensive overlying soft tissue envelope(47,48,56); however, a systematic review comparing various approaches found the posterolateral to be associated with the highest rate of wound complications (23%), and the medial approach has the lowest reported rate of ORIF-related complications, infection, and wound dehiscence(53,57). Compared to the posteromedial approach, the posterolateral allows a similar visualization of the posterior pilon plus access to the distal fibula without the risk of injury to the tibial neurovascular bundle(28).
6. Posteromedial: This is performed with the patient in the prone position and a cushion placed under the foot. The length depends on the metaphyseal-diaphyseal extent of the injury, starting 3 cm above the tuberosity of the calcaneus between the Achilles tendon and the medial malleolus, avoiding the peritendineum of the Achilles tendon. Deep dissection is continued in the interval between the tibial neurovascular bundle medially and the flexor hallucis longus tendon laterally. The tibiotalar joint and the fibular notch are partially exposed, and intercalary fragments are resected or reduced depending on size. Once correct reduction is achieved, it is fixed with Kirschner wires (K-wires), and then a buttress plate is applied with cortical or locking screws. It is crucial to assess the stability of the syndesmosis with either the hook test or external rotation test since although the literature supports that the reduction of the pilon fragment or posterior malleolus would be enough to restore it, in some cases, it remains unstable and requires fixation(3,58,59).

This approach allows for broad visualization of the posterior pilon, enabling the possibility of fixing both the posterolateral and posteromedial fragments, particularly in posterior malleolar fractures with joint impaction ("posterior pilon variant")(60). This approach lies close to the tibial neurovascular bundle with a high risk of injury or at least irritation, while a low rate of sural nerve and peroneal artery injury is reported, which perforates the interosseous membrane 4 to 6 cm from the tibial plafond(61). To avoid wound complications, a curved incision above the three main branches of the posterior tibial artery, the angiosomes of the medial and plantar calcaneal branch is required with meticulous preparation of a full-thickness fasciocutaneous flap(62). This approach could also be performed in the supine position, with the patient's leg in a "4" position. This position allows for combining it with other approaches, such as the anterolateral, without turning the patient, resulting in a significantly shorter surgical time (107.5 minutes versus 141.9 minutes in one study) than the prone/supine group(59).

Multiple studies have compared various approaches to the tibial pilon. They must be interpreted cautiously due to the high variability of pilon fractures and associated soft tissue compromise, as well as varying surgical expertise with any individual approach. Ketz and Sanders(48) found a similar range of motion (ROM) and functional scores between anterior and posterolateral approaches(48). In contrast, Wei et al.(63) reported that anatomical reduction was best achieved through the posterolateral approach, followed by the anterior, anteromedial, and anterolateral(53,63). Chan et al.(64) found a higher nonunion rate in AO 43C3 fractures when a combined anterior and posterior approach was performed, while the reduction quality was similar when comparing the same type of fractures treated with only a single anterior approach(64). In a comparative study on 590 pilon fractures, the authors found an infection rate of 19% with no significant association with any particular approach. Still, they identified the need for soft tissue coverage and smoking as independent risk factors for developing infection(65). In a systematic review of 733 cases, Liu et al.(53) found the anterior approach to be associated with the overall best results despite a high proportion of type-C fractures(53).

It has been classically held that a 7 cm skin bridge must be maintained between different distal tibial approaches; however, this concept has been challenged(66,67). Three vascular territories have been described, arranged vertically, supplying the overlying soft tissue envelope of the ankle. If the incisions are vertical and parallel, the distance between them does not matter, and there would be no threat to the resultant skin bridge(62,66-68). In summary, the choice of approaches is individually tailored to the fracture pattern, avoiding excessive soft tissue dissection and periosteal stripping, and has to consider the treating surgeon's expertise with any given approach.

Early primary fixation

Several authors have supported the definitive treatment of pilon fractures at an early stage(37,69,70). This perspective is based on the understanding that prolonged delays in surgery may lead to less effective anatomical reduction and an increased risk of postoperative infections(69). Additional considerations are that spanning external fixation restricts early movement, which can result in ankle stiffness and inadequate cartilage nutrition(12). Further concerns include complex regional syndrome because of delayed definitive surgery and pin-track infection[12]. White et al.[37], in a series of 95 patients with AO/OTA 43C fractures, reported good outcomes and high-quality reduction with early primary ORIF within 48 hours of injury, with only 6% of deep infections[37]. Tang et al.[70] compared early definitive fixation with minimally invasive techniques in 23 patients treated within 36 hours after injury vs 23 patients managed with a staged protocol, finding no significant differences between the groups regarding soft tissue complications, fracture union, and functional scores[70]. Additionally, these authors noted an increase in mean operative time, union time, costs, and hospital stay in the delayed surgery group, concluding that early ORIF is a safe procedure comparable to the staged protocol when soft tissue conditions are acceptable[70]. Several recent studies found that early primary fixation compared favorably with a staged protocol in the hands of fellowship-trained orthopedic and trauma surgeons[71-73].

Several authors have identified a window between three and five days post-injury when soft tissue swelling is highly increased, suggesting that early ORIF should be performed during the first two days to prevent wound complications[74].

Early definitive ORIF requires the availability of an experienced team and operation room resources within 48 hours of the injury. The same principles for planning approaches, reduction, and fixation apply to staged protocol management. If these conditions are not met, primary closed reduction, external fixation, and patient transfer to an institution with adequate expertise will help avoid severe complications.

Surgical strategies

Many strategies for the reduction and fixation of pilon fractures have been proposed in the literature, mostly based on the principles by Rüedi, Allgöwer and Heim with numerous modifications[18]. There is poor evidence on the ideal approach because of the great variability of pilon fractures and associated soft tissue damage. Some general considerations will be discussed in the following.

The individual choice of approaches and fixation depends on the quality of the soft tissues and the major fracture pattern. Stable internal fixation of the three main pillars (columns) of the tibial plafond and centrally impacted fragments should be pursued in a 360-degree manner and may be achieved with even a single plate, depending on the individual plate design[26,75]. The use of dual or triple plates should be weighed against the cost of extensive soft tissue dissection, unnecessary periosteal stripping, and compromise to the blood supply of the distal tibia with the risk of nonunion and osteonecrosis[75-79]. Likewise, fixation of the distal fibula as a "fourth column" is not generally indicated and may even negatively impact the reduction and healing of the tibia fracture[79,80].

By anatomically reducing the joint surface first, a complex type C3 fracture can be simplified to a type A fracture (Figure 5), while in less complex intra-articular fracture patterns (type C1/2), the fracture may be converted into a type B fracture by fixing the larger joint-bearing fragment to the

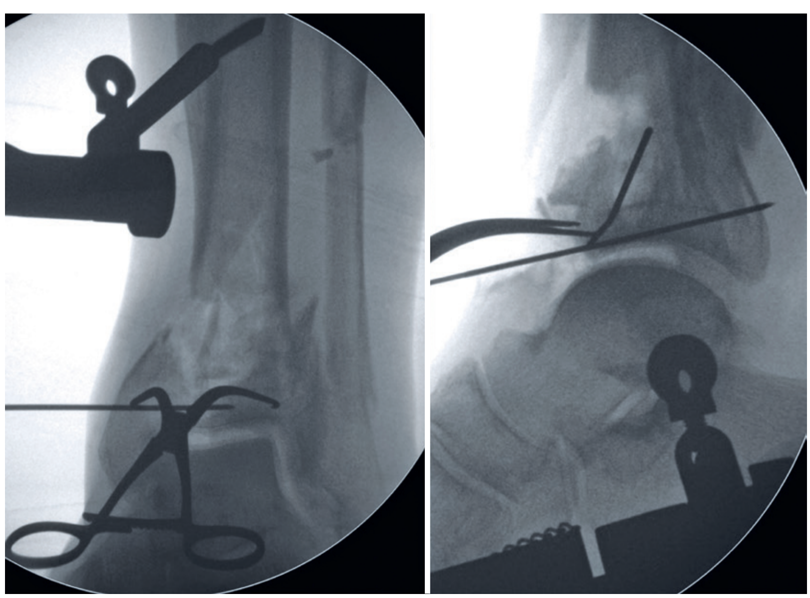

Figure 5. A central anterior approach is used for direct access into the main fracture line between the anterolateral and anteromedial fragments (same patient as in Figures 2-3). For complex articular fractures of the tibial plafond, starting with the joint reconstruction is useful, turning a type C into a type A fracture as long as all fragments are mobile. The tibial and calcaneal pins of the external fixator are draped free and may be used for joint distraction for both ligamentotaxis and enhanced overview over the joint surface. The tibial plafond is reconstructed step-wise from posterior to anterior and lateral to medial. The reduced fragments are temporarily held with pointed reduction clamps and Kirschner wires.

tibial metaphysis[18]. In type C3 fractures, there is no place for indirect reductions, and each fragment must be addressed through open reduction and direct visualization.

During reduction, it is important to consider displacement of the peroneal tendons (as reported in 90.9% of cases in a CT study), along with entrapment of the posteromedial flexor tendons and the posterior tibial neurovascular bundle as seen in approximately 10% of cases to avoid poor reduction of the fracture, impaired tendon function, and neurovascular injury[81,82].

An anterior approach is often used to reduce the joint pressure under direct visualization. One tibial and calcaneal Schanz screw from the external fixator may be kept in place to be used for distraction to gain a complete insight into the fractured tibial joint surface (i.e., by using a femoral distractor- see also Figure 5). The exact position of the approach (anteromedial vs. central vs. anterolateral) is chosen close to the main anterior fracture line to minimize soft tissue dissection and periosteal stripping. The anterolateral and anteromedial fragments are gently separated, and the central, posteromedial, and posterolateral fragments are identified. The latter may be considered a constant reference fragment for starting the reconstruction from posterior to anterior and lateral to medial[52]. Distraction can be relieved, and the talar dome is used as a template for realigning the central impacted (die punch) fragments[18]. Reduced articular fragments can be temporarily fixed with K-wires that may be driven out posteriorly. The anterolateral and anteromedial fragments are then reduced to the posterior and central fragments, and the K-wires are driven back from posterior to anterior, thus completing the reconstruction of the joint surface and turning the type C into a type A fracture. The K-wires may be exchanged with independent screws or resorbable implants. Small articular fragments may be cut flush with the anterior and posterior cortex and left in situ as "lost K-wires." Lag screws should only be used for simple fracture patterns. After joint reconstruction, the metaphysis is stabilized to the diaphysis with plate(s) and screws adapted to the individual fracture pattern and soft tissue conditions (Figure 6). If the main fracture line runs in the frontal plane, it is mechanically superior to place the plate anteriorly or posteriorly on the tibia[48]. If the main fracture line is situated in the sagittal plane, it is preferable to put the plate on the medial side to position the screws perpendicular to the fracture line.

Autografts or allografts may be utilized for larger defects resulting from bone loss or extensile metaphyseal comminution, although clinical evidence does not support it[83].

If a posterior approach is chosen, fixation of the posterior pilon is ideally performed with a posterior buttress antiglide plate. If a staged procedure is planned, care should be taken that the screws do not interfere with later anterior fragment fixation[48].

Definitive treatment

The principles of internal fixation are direct reduction and stable fixation of the articular surface, followed by restoration of metaphyseal length, rotation, alignment, and stabilization towards the tibial shaft spanning any comminuted metaphyseal fracture while minimizing any compromise to the soft tissues[84]. The options for definite fixation will be discussed in the following.

Intramedullary fixation

In diaphyseal comminution of the tibia with extension into the joint and poor soft tissue envelope, intramedullary nails (IMN) may be an option for internal fixation of simple articular fractures. The tibial plafond has to be fixed first with screws to avoid further fracture dislocation while introducing the nail. Joint reduction is controlled via a small, direct incision. If nondisplaced, the plafond fragments may be fixed with percutaneous screws. Marcus et al.[85] performed IMN in 23 patients with AO/OTA 43C1 fractures, achieving union at 14.1 weeks with excellent alignment, 8% infection, and 0% nonunion[85].

Goodnough et al.[86] described a reportedly safe technique that involves the use of a percutaneous, intramedullary screw placed from the medial malleolus, traversing the fracture site, with a bicortical tibial fixation on the contralateral side as medial support alongside less invasive anterolateral plate fixation in cases of fractures with metaphyseal involvement[86].

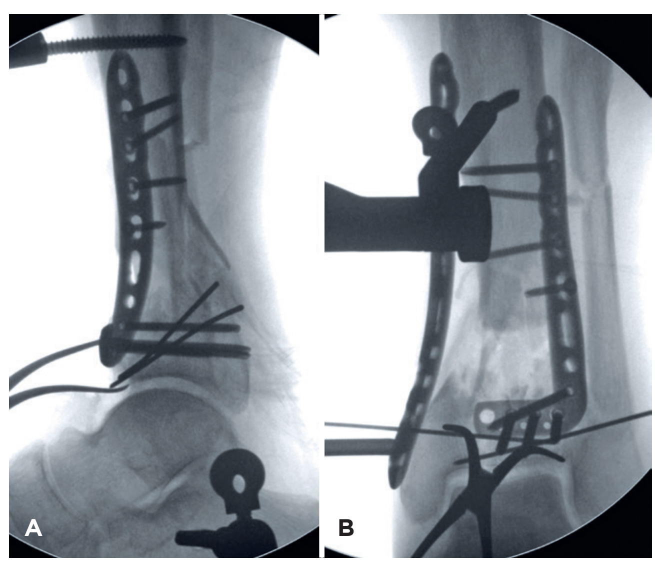

Figure 6. (A) Following joint reconstruction, the reconstructed joint block is aligned to the tibial shaft, and the metaphyseal zone of comminution is bridged by a locking anterolateral distal tibia plate that is slid in epiperiosteally and fixed in the proximal fragment via stab incision. (B) A medial buttress plate is introduced via minimal incisions in a minimally invasive plate osteosynthesis technique (same patient as in Figures 2-4).

Plate fixation

Many designs of pre-contoured distal tibia plates for pilon fractures have been described[66,75]. The objective is to span the metaphyseal comminution, thereby serving the function of bridge plates and promoting secondary bone healing through callus formation via endochondral ossification[78,84]. Using two or more plates can negatively impact callus formation if the construct is overly rigid[78]. On the other hand, the absence of implants on the medial or lateral side of the tibia may result in a weaker construct, leading to secondary subsidence in the coronal plane[78,84]. Campbell et al.[78] identified that placing one plate provides more callus formation at six months than dual plate fixation in a study of 50 patients with AO/OTA C2 or C3 fractures without impacting the reoperation rate[78]. Various authors have pondered whether the placement of these plates and their respective screws would be capable of stabilizing the three reference fragments (anterolateral, posterolateral, and medial). In a study using synthetic distal tibia sawbones, Penny et al.[75] demonstrated that three of four available anterolateral plates lacked stable fixation in the medial fragment with at least two screws. On the other hand, medial plates did not stabilize the anterolateral and posterolateral fragments with at least two screws (which are considered necessary to prevent rotation)[75]. Only screw insertion through the anterolateral variable angle plate could stabilize all three fragments[75]. A similar study performed in bone models based on fracture patterns in 162 patients AO/OTA 43C3 comparing three different models of anterolateral plates concluded that none of the three models could fix the medial malleolar fragment, and the Volkmann fragment was missed in 1.2% to 3.6% of cases[87]. Lack of medial support may lead to late varus deformities and nonunions[88]. From the available data, it appears that the anterolateral plate is most important for buttressing the area of greatest comminution, and the screws inserted through a variable angle plate can fix the three main fragments. To create a stiffer construct, particularly in more complex fracture patterns, the addition of a second (medial) plate or independent screws should be considered depending on the fracture pattern (Figure 6).

If possible, further damaging already compromised tissue plates should be inserted in a minimally invasive plate osteosynthesis (MIPO) technique to avoid extensive soft tissue and periosteum dissection. Alignment, length, and rotation of the distal tibia can be restored through indirect fracture manipulation of the diaphyseal and metaphyseal region, resulting in the preservation of periosteal blood supply and a lower rate of complications[89]. Extraarticular intercalary fragments are indirectly reduced without being stripped of their blood supply, thereby preserving bone biology. Percutaneous plates introduced and fixed via stab incisions may be useful on the medial aspect of the tibia due to less disruption to the extraosseous blood supply[12,90]. In a systematic review, it was reported that through the MIPO technique, an 87% rate of excellent to good results was achieved, comparable to ORIF, with a complication rate of 35%, including superficial infections (4.3%), only one case of deep infection, nonunions in 0.6%, and malunions in 3.%. and adequate quality of reduction[91]. A purely MIPO technique should be reserved for selected pilon fractures with a predominance of large fragments without substantial articular comminution[18]. Typically, the anterolateral plate is placed through an anterior incision that is also used for an anatomic joint reduction but slid in proximally bridging the zone of metaphyseal comminution, and the proximal screws are inserted into the diaphysis via stab incisions, while a second, medial plate, may be introduced in a MIPO technique (see Figure 6)[18,92].

External fixator

Keeping an external fixator as definitive fixation should be reserved for patients with significant wound compromise, bone loss, severe underlying comorbidities, infections, or unreconstructable injuries. In this case, the objective is to restore a functional limb while minimizing the risk of further complications[36]. Ideal indications are low fractures with minimal metaphyseal extension, partial articular fractures, and non-comminution[36]. To add additional construct stability, fixation with two mini-fragment plates has shown sufficient reduction maintenance over time[75].

The main advantages are a lower infection rate; however, complications such as articular malreduction, metaphyseal malalignment, ankle stiffness, loss of reduction, and malunion have also been described, leading to inferior outcomes compared with standard open reduction and internal fixation[45,93]. Richards et al.[94] compared 60 patients treated with ORIF vs. definitive external fixation with no difference in the quality of articular reduction. Delayed union and nonunion were more frequent in the external fixation group, and Iowa Ankle Scores and The 36-Item Short Form Health Survey (SF-36) scores were better in the ORIF group[94]. Zhao et al.[95] assessed 21 type C pilon fractures treated with an external fixator combined with limited open reduction and absorbable internal fixation. The results were satisfactory, with a union time of 4.8 months, superficial infection in eight patients, deep infection in one but no malunion, loss of reduction, or nonunion[95].

Another option for this complex injury is a circular external fixation with small wire or hybrid fixators. This construct allows for injury management with less soft tissue disruption and early weight bearing, also offering the possibility to perform gradual correction after initial surgery[36]. When using a circular small wire frame, an ankle sparning construct may be employed to allow for early motion[96]. In simple intraarticular fracture patterns, percutaneous joint reduction may be controlled arthroscopically[96]. Bacon et al.[97] did not find statistically significant differences in malunion, time to union, infection, or complication rates in pilon fractures treated with an Ilizarov frame or open plating[97]. Bastías et al.[33] compared 30 patients who received traditional ORIF vs 23 patients who underwent hexapod ring fixation for AO/OTA 43C3 pilon fractures; minor complications such as superficial infection and malalignment were significantly higher in the hexapod group; however, the ORIF group had higher major complications such as deep infection(33). Other reported complications by these authors, such as nonunion, reoperations, or ankle osteoarthritis, were not significantly different between groups, concluding that using the hexapod fixator, patients could achieve high union rates associated with low complications(33). External fixation remains a troubleshooter in any case of poor soft tissue conditions or any complication requiring the removal of all internal fixation.

Primary arthrodesis

Irrespective of the type of ORIF, pilon fractures carry an inherent risk of early osteoarthritis with chronic residual pain due to articular comminution with severe chondral damage, soft tissue damage, and bone stock loss(7,98). Age should not be a determining factor when deciding between arthrodesis and ORIF, as patients over 60 have shown similar results in treatment failure, bone loss, and malreduction compared to young patients(99). Zelle et al.(100) performed ankle arthrodesis with a posterior blade plate on 17 patients with AO/OTA C2 and C3 who presented more than 50% impaction and extensive comminution with results comparable to patients undergoing ORIF. They reported neither deep infections nor malunion, with union achieved at 132 days(100). Nicholas et al.(101), in their systematic review, found that primary ankle arthrodesis yields reasonable results in pilon fractures; however, only eight studies with 109 patients were eligible for the review, and many of them had inadequate follow-up(101). Beckwitt et al.(102) reported even better Foot and Ankle outcome scores (FAOS) after primary arthrodesis than ORIF(102). Arthrodesis can be performed using an anterior plate, a posterior blade plate, an external fixator, or an intramedullary nail (100,103). Using an external fixator provides long-term stable fixation with a low risk of infection (apart from pin-tracks), allowing distraction osteogenesis in case of significant bone loss(104). Solid fusion was achieved in one study at nine months in 12 of 14 patients (nine were talus fracture-dislocations) using a hexapod (Taylor Spatial Frame) external fixation with good results (SF-36 of 65, Ankle Osteoarthritis Score (AOS) 36.5 with 69.3% of scores graded good to excellent) without developing deep infection(105). Arthrodesis using a retrograde intramedullary nail allows stable hindfoot fixation through minimally invasive incisions, thus avoiding potential wound complications, but additionally sacrifices the subtalar joint(106). The inherent disadvantages of arthrodesis compared with joint-preserving procedures are decreased gait velocity, cadence, and stride length(107).

Open pilon fractures

The rate of open pilon fractures has been reported to be as high as 20%(108). This relatively high incidence is due to the thin and vulnerable soft tissue envelope surrounding the distal tibia, which is susceptible to disruption with injury(109). Such a scenario is challenging and is associated with a 10.5% to 18.8% risk of deep infection(44,110). However, if an appropriate treatment based on aggressive irrigation and debridement is followed by early soft tissue coverage, low nonunion rates, and infection could be achieved(3).

The classic protocol for open fractures includes debridement of devitalized bony and associated soft tissue followed by ankle-spanning external fixation. Lim et al.(9) treated 20 patients with open pilon fractures managed through early wound debridement, spanning external fixation (delta or rectangular frame), delayed soft tissue coverage with a flap when necessary, and delayed definitive fixation using a fine wire fixator (Ilizarov or Taylor) once the soft tissue was sufficiently healed(9). Bone union was achieved in 19 patients at a mean time of 10.4 months. The AOFAS score at 12 months was 74.2, with a 50% incidence of post-traumatic arthritis due to anatomical reduction in only 50% of the cases(9). The reported nonunion rates after open pilon fractures are also significant, ranging from 6% to 42%(3). Olson et al.(111) compared patients who suffered AO/OTA 43C fractures treated surgically within 24 hours (36 patients) with those treated after more than 24 hours (125 patients). The incidence of open fractures in their cohort was 22%(111). They reported a 27% rate of deep infection and a 22% rate of nonunion, with a statistically significant correlation between both variables. Their results indicated that patients who underwent early surgical intervention and presented with an open fracture Gustillo Anderson type 3A had a higher infection rate. The authors concluded that definitive treatment should not be performed during the initial management of an open fracture; rather, a staged protocol should be preferred. The same group identified factors such as male sex, smoking, connective tissue disease, and Gustilo Anderson type 3B fractures as associated with a higher infection rate(111). Siluzio et al.(3) reported a mean AOFAS score of 71.5 at 12 months in 14 patients who sustained AO/OTA 43C open pilon fractures (Gustilo Anderson 3 A-C), with 28% deep infections, 43% superficial infections, and 43% delayed union after staged management(3). In cases where the soft tissues do not allow for primary closure, negative pressure wound therapy can be useful until the inflammation subsides and a delayed closure or eventual flaps or grafts can be planned(112). Temporary placement of an antibiotic cement spacer is a useful adjunct in cases of bone loss during the initial trauma, as it fills the defect, creates an antimicrobial local environment, and a vascularized envelope for further grafting ("periost-like membrane")(113). Factors that predict soft tissue complications include falls from a height greater than 3 meters, segmental fibular fractures, and multifragmentary articular tibial fractures. These factors suggest that the higher the energy involved in the injury mechanism, the greater the potential for soft tissue complications(114).

Posterior pilon fracture

Fractures of the posterior tibial rim have a 46% association with Weber B or C distal fibular fractures(115). The term posterior malleolus (or posterior pilon) is defined based on whether the fragment involves up to (or more than) 50% of the tibial incisura and whether the medial malleolus is fractured in the intracollicular groove or as a whole[28]. Regardless of this definition, fixation of the posterior tibial fragments is crucial to restoring syndesmotic integrity, the tibiofibular incisura, thus facilitating anatomic reduction of the distal fibula[29,116]. Failure to reduce posterior fragments has been related to persistent posterior talar subluxation[117]. Attempts to fix the posterior malleolus through indirect reduction or fixation will likely yield non-anatomic reduction and poor results[29]. These results were supported by Ketz and Sanders[48], who performed staged posterior tibial plating for posterior malleolar fractures associated with 43C2 and 43C3 pilon fractures[48]. In nine cases, they performed a posterolateral approach for the posterior malleolus and a secondary anterior approach for the pilon fracture through a standard anterior midline incision, averaging 18.5 days apart. During this time, the fractures were temporarily stabilized with an external fixator, and another CT was performed to assess the quality of reduction and fixation of the posterior fragment(s). The quality of reduction and functional outcome were superior to ten patients in whom an anterior or anteromedial approach was utilized for the pilon fracture, along with an indirect reduction of the posterior malleolus fracture[48]. However, the overall number in both groups was small, and in a follow-up study from the same institution with 116 patients, of whom 35 underwent staged fixation of the posterior malleolar component, there was no statistically proven benefit regarding the quality of articular but a significantly higher risk of nonunion associated with multiple (posterior-anterior) approaches compared to a single (anterior-alone) approach[64]. Besides posterolateral (or posteromedial) approaches, the posterior malleolus component can also be reduced via a trans-fibular approach, providing direct visualization if the fibular fracture is in line with the posterior malleolar fracture, which is rather the case in rotational injuries and less common in pilon fractures[55].

Unlike classic tibial pilon fractures resulting from axial impact, isolated posterior tibial pilon fractures are considered lower energy and frequently occur in elderly patients[118-120]. In these cases, single posterior approaches will be performed, and the soft tissue cover in this region will result in a lower risk of wound dehiscence and infection[119,120].

What about the fibula?

Fibula fractures occur in more than 90% of cases of type C pilon fractures[121]. Its incidence is directly associated with a higher energy of the initial trauma[121]. Luk et al.[122] compared 36 tibial plafond fractures with an intact fibula against 71 pilon fractures in association with fibula fractures and stated that the group with an intact fibula was more commonly associated with AO type B patterns, and the group with pilon and fibula fractures was more associated with type C patterns[122].

Historically, reduction and fixation of the fibula in these types of fractures were considered fundamental to treatment success[14]. The objective was to achieve proper fibular length, alignment, and rotation to reduce the tibial plafond through ligamentotaxis and to prevent angular displacement in any plane by stabilizing the lateral column[123]. Other considerations for fixing the fibula included shortening, comminution, or distal fractures that would violate the syndesmosis[85]. In one study, the fibula length strongly correlated with the Foot and Ankle Ability Measure (FAAM) among 13 radiographic parameters [124]. Korkmaz et al.[1] reported that patients with an associated fibular fracture fixed with a plate had a statistically significant better range of ankle motion than those with unfixed fibula[1].

On the other hand, Kurylo et al.[125] found no statistically significant differences between 26 patients with fibular fracture fixation, 37 with fibular fractures unfixed, and 30 without fibula fractures in postoperative or final alignment, concluding that fixing the fibula is not always necessary[125]. In a similar study, Hong et al.[80] compared 25 patients who underwent fibular fixation with 29 patients in whom only tibial pilon fixation was performed. There were no statistically significant differences in outcomes or complication rates[80]. The authors concluded that fibular fixation is not necessary unless additional stability is desired or it aids in the reduction of the tibial pilon fracture[80]. If fibular fixation is performed, several authors recommend starting with fibular alignment in AO type 43 A or B pilon fractures, as there is no significant articular compromise of the distal tibia[83,125]. However, starting with the fibula should only be contemplated in simple fractures, where achieving adequate alignment, rotation, and length would facilitate tibial reduction[18]. With significant comminution of the fibula and all AO 43 C tibial fractures, there is consensus to begin with the reconstruction and alignment of the tibial plafond joint surface (Figure 7)[18].

Figure 7. The fibula is fixed last with a long plate bridging both fracture levels applied in a minimally invasive plate osteosynthesis technique (same patient as in Figures 2-5).

In summary, fibular fixation is not generally indicated in treating tibial pilon fractures. It may be considered individually in severe pilon fractures to maintain length and alignment of the tibia, to augment tibial fixation in case of poor bone quality, or to prevent soft tissue prominence of the displaced fibula[80]. During initial closed reduction and external fixation, primary fibular fixation may add to the soft tissue compromise, prevent proper manipulation of the distal tibia, or even interfere with the choice of approaches.

Syndesmotic injuries

Syndesmotic injuries and syndesmotic equivalent injuries, i.e., avulsions at the tubercule de Chaput or posterior malleolus ("Volkmann fragment"), have been reported in 3.4 to 25% of pilon fractures, particularly in those with bifocal fibula fractures[126-128]. Purcell et al.[128], in a retrospective study comparing pilon fractures with and without syndesmosis injury, concluded that this type of associated injury implies a higher energy trauma and can lead to a greater number of reoperations, neurovascular injuries, and even amputation[128]. Likewise, Christensen et al.[127] saw significantly worse outcomes in pilon fractures associated with syndesmotic injuries[127]. Haller et al.[126], in an analysis of 735 pilon fractures, found missed syndesmotic injury to be associated with the development of post-traumatic arthritis in 13 of 14 cases. In the same study, patients with a Chaput or Volkmann fragment greater than 10 mm significantly benefited from the fixation of these fragments[126]. Malposition of the syndesmosis, defined as > 2 mm difference in tibiofibular relationship to the uninjured side, is not uncommon (16 of 26 patients in one study) and was associated with inferior outcomes as measured by significantly lower FAAM and Activities of daily living (ADL) scores [129]. Like in complex malleolar fractures, restoring normal tibiofibular relationships, including anatomic reduction and fixation of syndesmotic avulsions in pilon fractures, appears essential for obtaining favorable results and avoiding post-traumatic arthrosis [129].

Aftercare

Following ORIF of closed pilon fractures, a well-padded posterior splint is applied, followed by a removable walker boot. Range of motion exercises are initiated after soft tissue consolidation. Patients are restricted to partial weight-bearing on two crutches in a walker boot for 8-12 weeks, depending on the individual fracture pattern, bone quality, and comorbidities. Patients who cannot walk on crutches are subject to non-weight-bearing in a wheelchair. In case of doubt about the quality of reduction and bony consolidation, CT scanning is employed (Figure 8). Regular weight-bearing radiographs are advised to assess fracture consolidation (Figure 9).

Complications

Because of the high trauma energy, the initial bone and cartilage damage due to the impaction, and the vulnerable soft tissue cover, complications are common in pilon fractures, including wound compromise, infection, nonunion, malunion, post-traumatic osteoarthritis (PTOA) and osteonecrosis[7,130]. PTOA is the most recognizable long-term disability, which has been reported in more than 50% of patients within four years after the injury[131,132]. The onset of early arthritis is directly related to poor anatomical reduction due to load transfer within the articular surface and is, in turn, associated with significant functional impairment[133,134]. This scenario is more frequent in pilon fractures treated with external fixation only[135]. If detected early, intraarticular osteotomies following the original fracture pattern could be performed in selected patients who are young and active, with good bone stock, compliance, and sufficient cartilage cover over the weight-bearing areas[136].

However, PTOA may also be caused by primary chondral damage due to axial forces during the initial trauma, despite further anatomical joint reconstruction[134,137]. DeCoster et al.[138] found reduction quality correlating with PTOA but not with medium-term functional outcomes[138]. Jo et al. demonstrated that pilon fractures associated with anterior impaction were significantly associated with advances in PTOA and anterior talar subluxation at 25 months compared to patients with other types of pilon fractures[139].

Willey et al.[140] found a 21% decrease in joint space in the injured ankle in weight-bearing computed tomography (WBCT) at six months in 20 patients who underwent ORIF for pilon tibial fracture, with the middle lateral and middle central regions showing the largest decrease[140]. Fortunately, radiological arthritis does not necessarily correlate with the same degree of symptoms, meaning that only about one-third of the patients may need further surgery like cheilectomy, debridement, joint distraction, ankle fusion, or total ankle replacement[136].

In the presence of early PTOA with focal defects no bigger than 1x1cm^2 after pilon fractures in young patients, osteochondral autograft in combination with ankle distraction and supra malleolar osteotomy in case of coronal malalignment may prevent rapid progression of osteoarthritis[141].

The use of external fixation does not preclude complications such as pin site infections in 20%[142], superficial infections in 6%[143], deep infection in 8%-17%[144], delayed bone union in 4%[145], inadequate union, nonunion, and initial loss reduction in 30%[146]. Lu et al. compared ORIF vs. external fixation, concluding that superficial infections were higher in the external fixation cohort than in the ORIF cohort; however, comparing those different patient cohorts should be viewed cautiously[147].

Nonunions are reported in 2-10% of cases and have been associated with fracture comminution, open fracture, soft tissue compromise, and smoking[148,149]. Treatment options include autologous bone grafting and augmentation of the construct using plates, nails, or external fixation[150].

Osteonecrosis is linked to certain fracture patterns, such as comminution, the presence of a small anterolateral fragment (< 2 cm^2), and the use of calcium phosphate bone substitutes[151]. One study identified osteonecrosis in 18 out of 69 patients at a follow-up of 7.3 months[151].

The most dreaded complication is a deep infection, which has been reported to occur in 2 to 16.7%[57]. Several risk factors for the development have been identified like Gustilo-Anderson type 3A or 3B open fracture, medial or anterior open wound, segmental bone loss or the need for soft tissue coverage, diabetes mellitus, comminuted fractures, smoking, male gender, advanced age, and high-energy trauma[57,73,152]. Correct soft-tissue management is critical to avoid the complications mentioned above, including a staged protocol, identifying the optimal window to perform

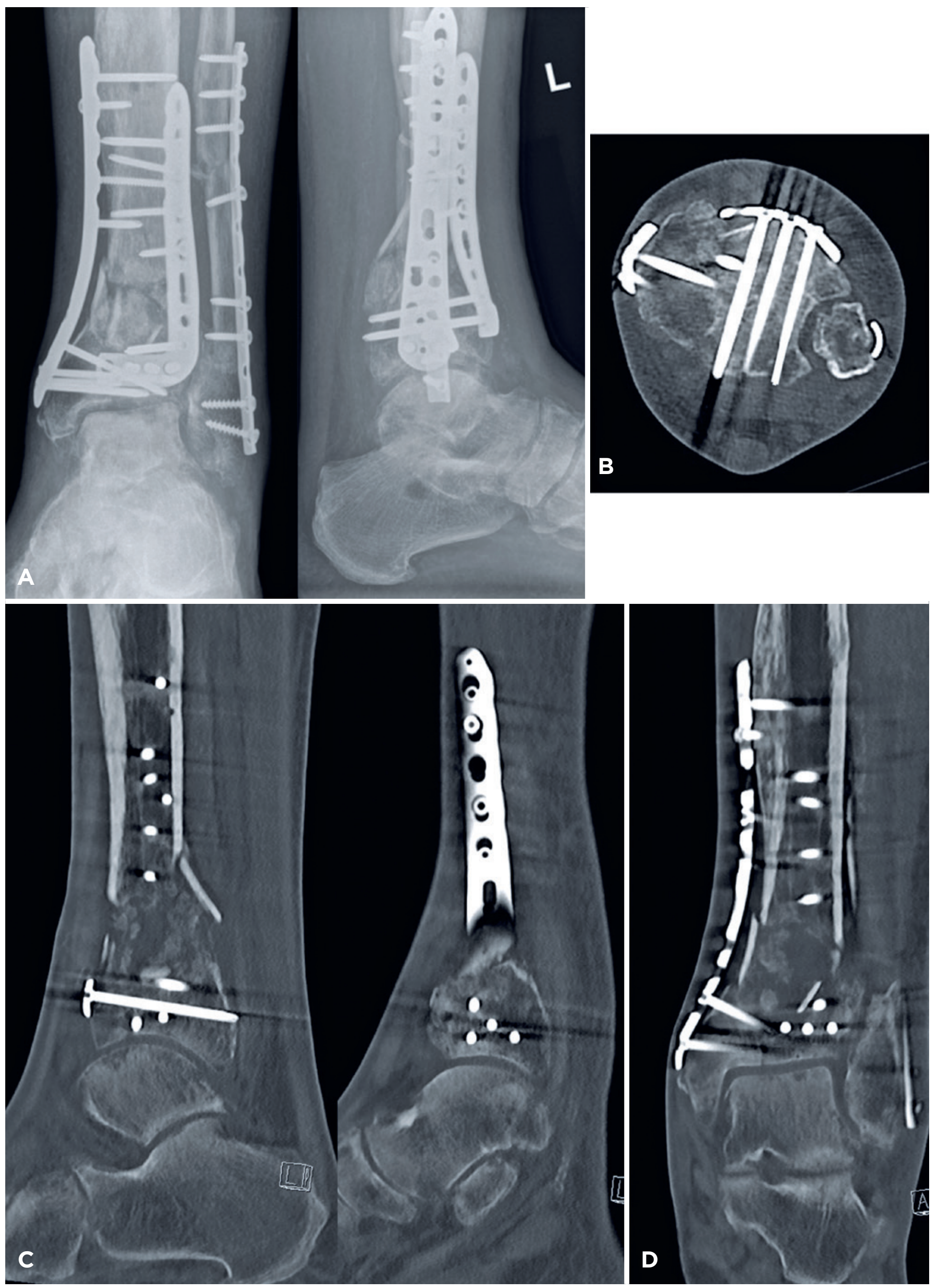

Figure 8. (A) Postoperative radiographs, (B) axial, (C) sagittal, and (D) coronal computed tomography scans showing anatomical restoration of the joint surface and the axial realignment to the tibial diaphysis (same patient as in Figures 2-6).

ORIF, avoiding aggressive reconstructive maneuvers, using atraumatic techniques, meticulous debridement, employing vacuum-assisted closure devices, and being reasonable and suspicious to anticipate potential wound dehiscence with timely intervention by plastic surgeons[12,147]. The amputation rate following a deep infection in patients with pilon tibial fractures has been reported with an incidence of up to 15%[152]. Using Vancomycin and Tobramycin powder appears promising in reducing infection rates in high-risk open and closed fractures, including pilon fractures[153,154].

Prognosis

Despite appropriate treatment, pilon fractures still routinely result in long-term dysfunction and pain. Several authors have reported swelling rates ranging from 29% to 76%, pain at 33%, and ankle stiffness from 31% to 66% after type C pilon fractures[155-157]. Most patients regain about 75% of their former functionality (Figure 10); however, 50% of them experience some level of disability, pain, and difficulty when walking, and 30% of them had to change their jobs[155-158]. Several conditions, such as diabetes or smoking, have been demonstrated to worsen the prognosis in the treatment of pilon fractures, affecting bone union and functional outcomes[159]. Uncontrolled diabetic patients have a 3.8 times increased risk for overall complications[160-162]. Wheelwright et al. identified factors associated with high performance after a pilon fracture, including lower body mass index, closed fractures, and AO 43B fractures. An 8% decrease in the odds of body mass index was related to high-performance patients with every unit increase[10].

In their study, Korkmaz et al.[1] evaluated different variables that could influence outcomes: fracture type (Rüedi/Allgöwer type 3), surgical treatment, and quality of reduction in 118 patients with pilon fractures (43B3, C1, C2, and C3) treated individually with different external and internal fixation methods[1]. The most important finding from this study was the statistically significant correlation between the quality of reduction and functional scores, independent of the type of surgery performed, which is confirmed by numerous other clinical studies[48,91]. For the same reason, several studies reported poor results with purely external fixation for type C fractures[97,135].

Pollak et al.[156] also assessed patients who sustained type C pilon fractures treated by ORIF or external fixation. These patients reported scores significantly lower than age-matched controls, even worse than patients with hip fractures or chronic illnesses such as AIDS, coronary artery disease, or diabetes[156]. As a consequence, tight control of blood glucose levels, adequate nutrition and vitamin substitution, and abstaining from alcohol, smoking, and drugs are important adjuvant concepts in the overall management of patients with severe pilon fractures[163].

Kellam et al.[155] reported that functional outcomes (PROMIS PF) after AO/OTA 43B/C pilon fractures improved from six weeks until six months but not between six months and two years postoperatively[155]. Several studies consistently reported that the mean long-term patient-reported outcomes measured with validated scoring systems in patients who have suffered pilon fractures are significantly lower than those of age-matched healthy controls[158,164].

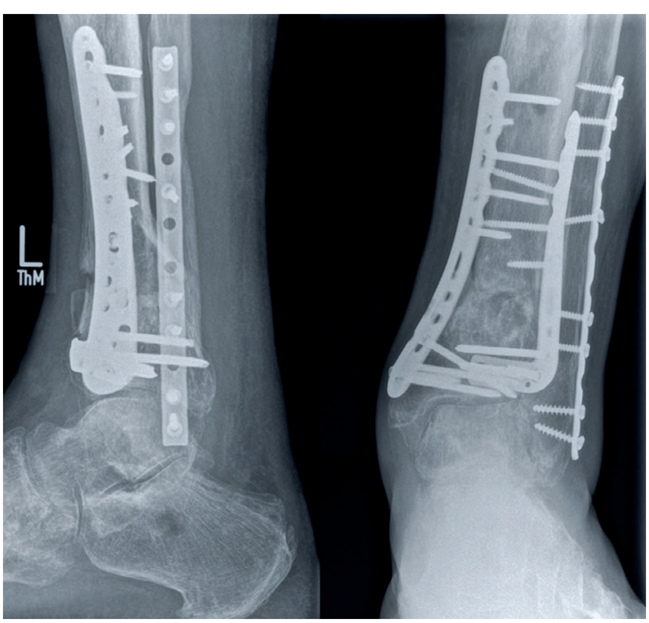

Figure 9. Standing radiographs at one year demonstrate consolidation of the fractures without loss of reduction or signs of early post-traumatic arthritis (same patient as in Figures 2-7).

Figure 10. (A) Clinical aspect and (B) ankle range of motion at one year. Note that the patient has a fused ankle on the right side from a previous accident (same patient as in Figures 2-8).

Authors' contributions: Each author contributed individually and significantly to the development of this article: FMZ *(https://orcid.org/0000-0002-6520-9775) Conceived and planned the activities that led to the study, approved the final version, interpreted the results of the study; GV *(https://orcid.org/0009-0008-7061-029X) Interpreted the results of the study, participated in the review process, and approved the final version; SR *(https://orcid.org/0000-0003-1141-6493) Approved the final version, conceived and planned the activities that led to the paper, have interpreted the results achieved. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Korkmaz A, Ciftdemir M, Ozcan M, Copuroğlu C, Sarıdoğan K. The analysis of the variables, affecting outcome in surgically treated tibia pilon fractured patients. Injury. 2013;44(10):1270-4.
2. Zeng XT, Pang GG, Ma BT, Mei XL, Sun X, Wang J, et al. Surgical treatment of open pilon fractures. Orthop Surg. 2011;3(1):45-51.
3. Silluzio N, De Santis V, Marzetti E, Piccioli A, Rosa MA, Maccauro G. Clinical and radiographic outcomes in patients operated for complex open tibial pilon fractures. Injury. 2019;50:S24-8.
4. Tomás-Hernández J. High-energy pilon fractures management: State of the art. EFORT Open Rev. 2016;1(10):354-61.
5. Lou Z, Wang Z, Liu C, Tang X. Outcomes of tibial pilon fracture fixation based on four-column theory. Injury. 2023;54 Suppl 2: S36-42.
6. Michelson J, Moskovitz P, Labropoulos P. The nomenclature for intra-articular vertical impact fractures of the tibial plafond: pilon versus pylon. Foot Ankle Int. 2004;25(3):149-50.
7. Kottmeier SA, Madison RD, Divaris N. Pilon Fracture: Preventing Complications. J Am Acad Orthop Surg. 2018;26(18):640-51.
8. Bonar SK, Marsh JL. Tibial Plafond Fractures: Changing Principles of Treatment. J Am Acad Orthop Surg. 1994;2(6):297-305.
9. Lim JA, Thahir A, Zhou AK, Girish M, Krkovic M. Definitive management of open pilon fractures with fine wire fixation. Injury. 2020;51(11):2717-22.
10. Wheelwright JC, Christensen GV, Cizik AM, Zhang C, Marchand LS, Haller JM. Significant Factors of High Performance Outcomes for Tibial Plafond Fractures. Foot Ankle Int. 2022;43(10):1261-8.
11. Vetter SY, Euler F, von Recum J, Wendl K, Grützner PA, Franke J. Impact of Intraoperative Cone Beam Computed Tomography on Reduction Quality and Implant Position in Treatment of Tibial Plafond Fractures. Foot Ankle Int. 2016;37(9):977-82.
12. Tarkin IS, Clare MP, Marcantonio A, Pape HC. An update on the management of high-energy pilon fractures. Injury. 2008;39(2):142-54.
13. Cutillas-Ybarra MB, Lizaur-Utrilla A, Lopez-Prats FA. Prognostic factors of health-related quality of life in patients after tibial plafond fracture. A pilot study. Injury. 2015;46(11):2253-7.
14. 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.
15. Dirschl DR, Adams GL. A critical assessment of factors influencing reliability in the classification of fractures, using fractures of the tibial plafond as a model. J Orthop Trauma. 1997;11(7):471-6.
16. Martin JS, Marsh JL, Bonar SK, DeCoster TA, Found EM, Brandser EA. Assessment of the AO/ASIF fracture classification for the distal tibia. J Orthop Trauma. 1997;11(7):477-83.
17. Meinberg EG, Agel J, Roberts CS, Karam MD, Kellam JF. Fracture and Dislocation Classification Compendium-2018. J Orthop Trauma. 2018;32 Suppl 1:S1-170.
18. Rammelt S, Swords M, Dhillon MS. Manual of Fracture Management - Foot and Ankle. Thieme; 2019.
19. Topliss CJ, Jackson M, Atkins RM. Anatomy of pilon fractures of the distal tibia. J Bone Joint Surg Br. 2005;87(5):692-7.
20. Ramappa M, Bajwa A, Singh A, Mackenney P, Hui A, Port A. Interobserver and intraobserver variations in tibial pilon fracture classification systems. Foot. 2010;20(2-3):61-3.
21. Swiontkowski MF, Sands AK, Agel J, Diab M, Schwappach JR, Kreder HJ. Interobserver variation in the AO/OTA fracture classification system for pilon fractures: is there a problem? J Orthop Trauma. 1997;11(7):467-70.
22. Heim U. The Pilon Tibial Fracture: Classification, Surgical Techniques, Results. Saunders; 1995.
23. Leonetti D, Tigani D. Pilon fractures: A new classification system based on CT-scan. Injury. 2017;48(10):2311-7.
24. Cole PA, Mehrle RK, Bhandari M, Zlowodzki M. The pilon map: fracture lines and comminution zones in OTA/AO type 43C3 pilon fractures. J Orthop Trauma. 2013;27(7):e152-6.
25. Korrapati A, Ta CN, Mitchell BC, Wall PV, Gurusamy P, Dwight K, et al. Fracture blisters: predictors for time to definitive fixation in pilon fractures. Eur J Orthop Surg Traumatol. 2023;34(1):161-6.
26. Assal M, Ray A, Stern R. Strategies for surgical approaches in open reduction internal fixation of pilon fractures. J Orthop Trauma. 2015;29(2):69-79.
27. Chen H, Cui X, Ma B, Rui Y, Li H. Staged procedure protocol based on the four-column concept in the treatment of AO/OTA type 43-C3.3 pilon fractures. J Int Med Res. 2019;47(5):2045-55.
28. Bartoníček J, Rammelt S, Kostlivý K, Vaněček V, Klika D, Trešl I. Anatomy and classification of the posterior tibial fragment in ankle fractures. Arch Orthop Trauma Surg. 2015;135(4):505-16.
29. Rammelt S, Bartoníček J. Posterior Malleolar Fractures: A Critical Analysis Review. JBJS Rev. 2020;8(8):e19.00207.
30. Rammelt S, Bartoníček J, Schepers T, Kroker L. Fixation of anterolateral distal tibial fractures: the anterior malleolus. Oper Orthop Traumatol. 2021;33(2):125-38.
31. Rammelt S, Bartoníček J, Kroker L. Pathoanatomy of the Anterolateral Tibial Fragment in Ankle Fractures. J Bone Joint Surg Am. 2022;104(4):353-63.
32. Zhu G, Cao S, Zhu J, Yuan C, Wang Z, Huang J, et al. Combined vertical and external rotational force in plantarflexion position produces posterior pilon fracture: A preliminary cadaveric study. Foot Ankle Surg. 2024;30(5):394-9.
33. Bastías GF, Sepúlveda S, Bruna S, Contreras M, Hube M, Cuchacovich N, et al. Comparison of complications and reoperations in AO/

OTA 43.C3 pilon fractures treated with conventional ORIF versus minimally invasive hexapod ring fixation. Injury. 2023;54 Suppl 6:110884.
34. Patterson MJ, Cole JD. Two-staged delayed open reduction and internal fixation of severe pilon fractures. J Orthop Trauma. 1999;13(2):85-91.
35. Taylor BC, So E, Karim A. Spanning External Fixation for Pilon Fractures: Steering Wheel and Kickstands. Orthopedics. 2020; 43(3):e187-90.
36. Swords MP, Weatherford B. High-Energy Pilon Fractures: Role of External Fixation in Acute and Definitive Treatment. What are the Indications and Technique for Primary Ankle Arthrodesis? Foot Ankle Clin. 2020;25(4):523-36.
37. White TO, Guy P, Cooke CJ, Kennedy SA, Droll KP, Blachut PA, 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.
38. 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.
39. Ramlee MH, Kadir MRA, Murali MR, Kamarul T. Finite element analysis of three commonly used external fixation devices for treating Type III pilon fractures. Med Eng Phys. 2014;36(10):1322-30.
40. Watson JT, Moed BR, Karges DE, Cramer KE. Pilon fractures. Treatment protocol based on severity of soft tissue injury. Clin Orthop Relat Res. 2000;(375):78-90.
41. Tornetta P 3rd, Gorup J. Axial computed tomography of pilon fractures. Clin Orthop Relat Res. 1996;(323):273-6.
42. Keiler A, Riechelmann F, Thöni M, Brunner A, Ulmar B. Three-dimensional computed tomography reconstruction improves the reliability of tibial pilon fracture classification and preoperative surgical planning. Arch Orthop Trauma Surg. 2020;140(2):187-95.
43. Varela CD, Vaughan TK, Carr JB, Slemmons BK. Fracture blisters: clinical and pathological aspects. J Orthop Trauma. 1993;7(5):417-27.
44. Sirkin M, Sanders R, DiPasquale T, Herscovici D Jr. A staged protocol for soft tissue management in the treatment of complex pilon fractures. J Orthop Trauma. 2004;18(8 Suppl):S32-8.
45. Dickson KF, Montgomery S, Field J. High energy plafond fractures treated by a spanning external fixator initially and followed by a second stage open reduction internal fixation of the articular surface--preliminary report. Injury. 2001;32 Suppl 4:SD92-8.
46. Assal M, Ray A, Stern R. The extensile approach for the operative treatment of high-energy pilon fractures: surgical technique and soft-tissue healing. J Orthop Trauma. 2007;21(3):198-206.
47. Zwipp H, Rammelt S, Endres T, Heineck J. High union rates and function scores at midterm followup with ankle arthrodesis using a four screw technique. Clin Orthop Relat Res. 2010;468(4):958-68.
48. Ketz J, Sanders R. Staged posterior tibial plating for the treatment of Orthopaedic Trauma Association 43C2 and 43C3 tibial pilon fractures. J Orthop Trauma. 2012;26(6):341-7.
49. Kim GB, Shon OJ, Park CH. Treatment of AO/OTA Type C Pilon Fractures Through the Anterolateral Approach Combined With the Medial MIPO Technique. Foot Ankle Int. 2018;39(4):426-32.
50. Herscovici D Jr, Sanders RW, Infante A, DiPasquale T. Bohler incision: an extensile anterolateral approach to the foot and ankle. J Orthop Trauma. 2000;14(6):429-32.
51. Gulbrandsen TR, Hulick RM, Polk AJ, Weldy JM, Howell KL, Spitler CA, et al. Does surgical approach affect sagittal plane alignment and pilon fracture outcomes? Injury. 2020;51(3):750-8.
52. Müller FJ, Nerlich M. Tibial pilon fractures. Acta Chir Orthop Traumatol Cech. 2010;77(4):266-76.
53. Liu J, Smith CD, White E, Ebraheim NA. A Systematic Review of the Role of Surgical Approaches on the Outcomes of the Tibia Pilon Fracture. Foot Ankle Spec. 2016;9(2):163-8.
54. Rammelt S, Bartoníček J, Kroker L, Neumann AP. Surgical Fixation of Quadrimalleolar Fractures of the Ankle. J Orthop Trauma. 2021;35(6):e216-22.
55. Rammelt S, Zwipp H, Mittlmeier T. [Operative treatment of pronation fracture--dislocations of the ankle]. Oper Orthop Traumatol. 2013;25(3):273-91.
56. Neumann AP, Kroker L, Beyer F, Rammelt S. Complications following surgical treatment of posterior malleolar fractures: an analysis of 300 cases. Arch Orthop Trauma Surg. 2023;143(6):3129-36.
57. Spitler CA, Hulick RM, Weldy J, Howell K, Bergin PF, Graves ML. What are the Risk Factors for Deep Infection in OTA/AO 43C Pilon Fractures? J Orthop Trauma. 2020;34(6):e189-94.
58. Hoekstra H, Rosseels W, Rammelt S, Nijs S. Direct fixation of fractures of the posterior pilon via a posteromedial approach. Injury. 2017;48(6):1269-74.
59. Guo C, Zhu Y, Li C, Li X, Yang C, Xu X. Comparison of prone-supine versus supine position for the treatment of pilon fractures via modified posteromedial approach combined with anterolateral approach. Foot Ankle Surg. 2023;29(1):79-85.
60. Wang Y, Wang J, Luo CF. Modified posteromedial approach for treatment of posterior pilon variant fracture. BMC Musculoskelet Disord. 2016;17(1):1-8.
61. Lidder S, Masterson S, Dreu M, Clement H, Grechenig S. The Risk of Injury to the Peroneal Artery in the Posterolateral Approach to the Distal Tibia: A Cadaver Study. J Orthop Trauma. 2014;28(9):534.
62. Attinger CE, Evans KK, Bulan E, Blume P, Cooper P. Angiosomes of the foot and ankle and clinical implications for limb salvage: reconstruction, incisions, and revascularization. Plast Reconstr Surg. 2006;117(7 Suppl):261S - 293S.
63. Wei SJ, Han F, Lan SH, Cai XH. Surgical treatment of pilon fracture based on ankle position at the time of injury/initial direction of fracture displacement: a prospective cohort study. Int J Surg. 2014;12(5):418-25.
64. Chan DS, Balthrop PM, White B, Glassman D, Sanders RW. Does a Staged Posterior Approach Have a Negative Effect on OTA 43C Fracture Outcomes? J Orthop Trauma. 2017;31(2):90-4.
65. Esposito JG, van der Vliet QMJ, Heng M, Potter J, Cronin PK, Harris MB, et al. Does Surgical Approach Influence the Risk of Postoperative Infection After Surgical Treatment of Tibial Pilon Fractures? J Orthop Trauma. 2020;34(3):126.
66. 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.
67. Bartolozzi P, Lavini F. Fractures of the Tibial Pilon. Springer Science & Business Media; 2012.
68. 68.Aubry P, Fieve G. [Bone and skin vascularization of the lower 4th of the leg]. Rev Chir Orthop Reparatrice Appar Mot. 1984;70(8):589-97.
69. Høiness P, Strømsøe K. The influence of the timing of surgery on soft tissue complications and hospital stay. A review of 84 closed ankle fractures. Ann Chir Gynaecol. 2000;89(1):6-9.
70. 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.
71. Flanagan CD, Lufrano RC, Mesa L, Watson D, Shah AR, Maxson BJ, et al. Outcomes After Acute Versus Staged Fixation of Complete Articular Tibial Plafond Fractures. J Orthop Trauma. 2023;37(6):294-8.

72. Kim YJ, Richard RD, Scott BL, Parry JA. Acute Fixation Protocol for High-Energy Tibial Pilon Fractures Decreases Time to Fixation and Lowers Operative Costs Without Affecting Wound Complications and Reoperations. J Orthop Trauma. 2023;37(10):525-31.
73. Olson JJ, Anand K, von Keudell A, Esposito JG, Rodriguez EK, Smith RM, et al. Judicious Use of Early Fixation of Closed, Complete Articular Pilon Fractures Is Not Associated With an Increased Risk of Deep Infection or Wound Complications. J Orthop Trauma. 2021;35(6):300.
74. Wyrsch B, McFerran MA, McAndrew M, Limbird TJ, Harper MC, Johnson KD, et al. Operative treatment of fractures of the tibial plafond. A randomized, prospective study. J Bone Joint Surg Am. 1996;78(11):1646-57.
75. Penny P, Swords M, Heisler J, Cien A, Sands A, Cole P. Ability of modern distal tibia plates to stabilize comminuted pilon fracture fragments: Is dual plate fixation necessary? Injury. 2016;47(8):1761-9.
76. Menck J, Bertram C, Lierse W. Sectorial angioarchitecture of the human tibia. Acta Anat (Basel). 1992;143(1):67-73.
77. Van Rysselberghe NL, Campbell ST, Goodnough LH, Salazar BP, Bishop JA, Bellino MJ, et al. Metaphyseal callus formation in pilon fractures is associated with loss of alignment: Is stiffer better? Injury. 2021;52(4):977-81.
78. Campbell ST, Goodnough LH, Salazar B, Lucas JF, Bishop JA, Gardner MJ. How do pilon fractures heal? An analysis of dual plating and bridging callus formation. Injury. 2020;51(7):1655-61.
79. Bakan ÖM, Vahabi A, Özkayın N. Management of complex pilon fractures: Is it necessary to fix all the columns in AO/OTA type 43-C fractures? Injury. 2023;54(12):111153.
80. Hong CC, Tan SHS, Saha S, Pearce CJ. Fibula fixation in the treatment of tibial pilon fractures - Is it really necessary? Foot Ankle Surg. 2022;28(7):891-7.
81. Fokin A Jr, Huntley SR, Summers SH, Lawrie CM, Miranda AD, Caban-Martinez AJ, et al. Computed Tomography Assessment of Peroneal Tendon Displacement and Posteromedial Structure Entrapment in Pilon Fractures. J Orthop Trauma. 2016;30(11):627.
82. Eastman JG, Firoozabadi R, Benirschke SK, Barei DP, Dunbar RP. Entrapped posteromedial structures in pilon fractures. J Orthop Trauma. 2014;28(9):528-33.
83. New Principles in Pilon Fracture Management: Revisiting Rüedi and Allgöwer Concepts. Foot Ankle Clin. 2020;25(4):505-21.
84. Fractures of the Tibial Plafond. Foot Ankle Clin. 2008;13(4):571-91.
85. Marcus MS, Yoon RS, Langford J, Kubiak EN, Morris AJ, Koval KJ, et al. Is there a role for intramedullary nails in the treatment of simple pilon fractures? Rationale and preliminary results. Injury. 2013;44(8):1107-11.
86. Goodnough LH, Tigchelaar SS, Van Rysselberghe NL, DeBaun MR, Gardner MJ, Hecht GG, et al. Medial Column Support in Pilon Fractures Using Percutaneous Intramedullary Large Fragment Fixation. J Orthop Trauma. 2021;35(12):e502-6.
87. Aneja A, David Luo T, Liu B, Domingo M, Danelson K, Halvorson JJ, et al. Anterolateral distal tibia locking plate osteosynthesis and their ability to capture OTAC3 pilon fragments. Injury. 2018;49(2):409-13.
88. Haller JM, Githens M, Rothberg D, Higgins T, Nork S, Barei D. Risk Factors for Tibial Plafond Nonunion: Medial Column Fixation May Reduce Nonunion Rates. J Orthop Trauma. 2019;33(9):443-9.
89. Lau TW, Leung F, Chan CF, Chow SP. Wound complication of minimally invasive plate osteosynthesis in distal tibia fractures. Int Orthop. 2008;32(5):697-703.
90. Borrelli J Jr, Prickett W, Song E, Becker D, Ricci W. Extraosseous blood supply of the tibia and the effects of different plating techniques: a human cadaveric study. J Orthop Trauma. 2002;16(10):691-5.
91. Sourougeon Y, Barzilai Y, Haba Y, Spector B, Prat D. Outcomes following minimally invasive plate osteosynthesis (MIPO) application in tibial pilon fractures - A systematic review. Foot Ankle Surg. 2023;29(8):566-75.
92. Rubio-Suarez JC, Carbonell-Escobar R, Carlos Rodriguez-Merchan E, Ibarzabal-Gil A, Gil-Garay E. Fractures of the tibial pilon treated by open reduction and internal fixation (locking compression plate-less invasive stabilising system): Complications and sequelae. Injury. 2018;49:S60-4.
93. Pugh KJ, Wolinsky PR, McAndrew MP, Johnson KD. Tibial pilon fractures: a comparison of treatment methods. J Trauma. 1999; 47(5):937-41.
94. Richards JE, Magill M, Tressler MA, Shuler FD, Kregor PJ, Obremskey WT, et al. External fixation versus ORIF for distal intra-articular tibia fractures. Orthopedics. 2012;35(6):e862-7.
95. Zhao L, Li Y, Chen A, Zhang Z, Xi J, Yang D. Treatment of type C pilon fractures by external fixator combined with limited open reduction and absorbable internal fixation. Foot Ankle Int. 2013; 34(4):534-42.
96. Rammelt S, Endres T, Grass R, Zwipp H. The role of external fixation in acute ankle trauma. Foot Ankle Clin. 2004;9(3):455-74.
97. Bacon S, Smith WR, Morgan SJ, Hasenboehler E, Philips G, Williams A, et al. A retrospective analysis of comminuted intra-articular fractures of the tibial plafond: Open reduction and internal fixation versus external Ilizarov fixation. Injury. 2008;39(2):196-202.
98. Tochigi Y, Buckwalter JA, Martin JA, Hillis SL, Zhang P, Vaseenon T, et al. Distribution and progression of chondrocyte damage in a whole-organ model of human ankle intra-articular fracture. J Bone Joint Surg Am. 2011;93(6):533-9.
99. Haller JM, Githens M, Rothberg D, Higgins T, Nork S, Barei D. Pilon Fractures in Patients Older Than 60 Years of Age: Should We Be Fixing These? J Orthop Trauma. 2020;34(3):121.
100. 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.
101. Nicholas PRM, Carter R, Chan P, Jamal B. A Systematic Review Of Primary Ankle Arthrodesis In The Treatment Of Pilon Fractures. Foot. 2021;47:101780.
102. Beckwitt CH, Monaco SJ, Gruen GS. Republication of "Primary Ankle Arthrodesis vs ORIF for Severely Comminuted Pilon Fractures: A Comparative Retrospective Study." Foot Ankle Orthop. 2023;8(3):24730114231193391.
103. 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.
104. Paley D, Maar DC. Ilizarov bone transport treatment for tibial defects. J Orthop Trauma. 2000;14(2):76-85.
105. Ordas-Bayon A, Logan K, Garg P, Peat F, Krkovic M. Ankle arthrodesis using the Taylor Spatial Frame for the treatment of infection, extruded talus and complex pilon fractures. Injury. 2021;52(4):1028-37.
106. Hsu AR, Szatkowski JP. Early Tibiotalocalcaneal Arthrodesis Intramedullary Nail for Treatment of a Complex Tibial Pilon Fracture (AO/OTA 43-C). Foot Ankle Spec. 2015;8(3):220-5.
107. Thomas R, Daniels TR, Parker K. Gait analysis and functional outcomes following ankle arthrodesis for isolated ankle arthritis. J Bone Joint Surg Am. 2006;88(3):526-35.

108. 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.

109. Molina CS, Stinner DJ, Fras AR, Evans JM. Course of treatment and rate of successful salvage following the diagnosis of deep infection in patients treated for pilon fractures (AO/OTA: 43). J Orthop. 2015;12(Suppl 1):S18-24.

110. Guerra MTE, Gregio FM, Bernardi A, Castro CC de. Infection rate in adult patients with open fractures treated at the emergency hospital and at the ULBRA university hospital in Canoas, Rio Grande do Sul, Brazil. Rev Bras Ortop. 2017;52(5):544-8.

111. Olson JJ, Anand K, Esposito JG, von Keudell AG, Rodriguez EK, Smith RM, et al. Complications and Soft-Tissue Coverage After Complete Articular, Open Tibial Plafond Fractures. J Orthop Trauma. 2021;35(10):e371-6.

112. Henry SL, Ostermann PA, Seligson D. The antibiotic bead pouch technique. The management of severe compound fractures. Clin Orthop Relat Res. 1993;(295):54-62.

113. Masquelet AC. Induced Membrane Technique: Pearls and Pitfalls. J Orthop Trauma. 2017;31 Suppl 5:S36-8.

114. Heiner JA, Banner KA, Wu VJ, Achor TS, Gary JL, Munz JW, et al. The injury characteristics of open pilon fractures predictive of complications. Injury. 2022;53(4):1510-6.

115. Jehlicka D, Bartonícek J, Svatos F, Dobiás J. [Fracture-dislocations of the ankle joint in adults. Part I: epidemiologic evaluation of patients during a 1-year period]. Acta Chir Orthop Traumatol Cech. 2002;69(4):243-7.

116. Gardner MJ, Brodsky A, Briggs SM, Nielson JH, Lorich DG. Fixation of posterior malleolar fractures provides greater syndesmotic stability. Clin Orthop Relat Res. 2006;447:165-71.

117. Weber M. Trimalleolar fractures with impaction of the posteromedial tibial plafond: implications for talar stability. Foot Ankle Int. 2004;25(10):716-27.

118. Klammer G, Kadakia AR, Joos DA, Seybold JD, Espinosa N. Posterior pilon fractures: a retrospective case series and proposed classification system. Foot Ankle Int. 2013;34(2):189-99.

119. Chen DW, Li B, Aubeeluck A, Yang YF, Zhou JQ, Yu GR. Open reduction and internal fixation of posterior pilon fractures with buttress plate. Acta Ortop Bras. 2014;22(1):48-53.

120. 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.

121. Barei DP, Nork SE, Bellabarba C, Sangeorzan BJ. Is the absence of an ipsilateral fibular fracture predictive of increased radiographic tibial pilon fracture severity? J Orthop Trauma. 2006;20(1):6-10.

122. Luk PC, Charlton TP, Lee J, Thordarson DB. Ipsilateral intact fibula as a predictor of tibial plafond fracture pattern and severity. Foot Ankle Int. 2013;34(10):1421-6.

123. Babis GC, Vayanos ED, Papaioannou N, Pantazopoulos T. Results of surgical treatment of tibial plafond fractures. Clin Orthop Relat Res. 1997;(341):99-105.

124. 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.

125. Kurylo JC, Datta N, Iskander KN, Tornetta P 3rd. Does the Fibula Need to be Fixed in Complex Pilon Fractures? J Orthop Trauma. 2015;29(9):424-7.

126. Haller JM, Githens M, Rothberg D, Higgins T, Barei D, Nork S. Syndesmosis and Syndesmotic Equivalent Injuries in Tibial Plafond Fractures. J Orthop Trauma. 2019;33(3):e74-8.

127. Christensen GV, Wheelwright JC, Rothberg DL, Higgins TF, Marchand LS, Haller JM. Syndesmotic Injury in Tibial Plafond Fractures Is Associated With Worse Patient Outcomes. J Orthop Trauma. 2022;36(9):469-73.

128. Purcell KF, Bergin PF, Russell GV, Graves ML, Jones LC, Spitler CA. Tibial Shaft and Pilon Fractures With Associated Syndesmotic Injury: A Matched Cohort Assessment. J Orthop Trauma. 2022; 36(3):157-62.

129. Rooney P, Haller J, Kleweno C, Glass N, Davison J, Miller A, et al. Syndesmosis Malposition Assessed on Weight-Bearing CT Is Common After Operative Fixation of Intra-articular Distal Tibia Plafond Fracture. J Orthop Trauma. 2022;36(12):658-64.

130. McFerran MA, Smith SW, Boulas HJ, Schwartz HS. Complications encountered in the treatment of pilon fractures. J Orthop Trauma. 1992;6(2):195-200.

131. Zelle BA, Dang KH, Ornell SS. High-energy tibial pilon fractures: an instructional review. Int Orthop. 2019;43(8):1939-50.

132. Lee YS, Chen SW, Chen SH, Chen WC, Lau MJ, Hsu TL. Stabilisation of the fractured fibula plays an important role in the treatment of pilon fractures: a retrospective comparison of fibular fixation methods. Int Orthop. 2009;33(3):695-9.

133. Chen DW, Li B, Yang YF, Yu GR. Posterior pilon fractures. Foot Ankle Int. 2013;34(5):766-7.

134. Fitzpatrick DC, Otto JK, McKinley TO, Marsh JL, Brown TD. Kinematic and contact stress analysis of posterior malleolus fractures of the ankle. J Orthop Trauma. 2004;18(5):271-8.

135. Wang C, Li Y, Huang L, Wang M. Comparison of two-staged ORIF and limited internal fixation with external fixator for closed tibial plafond fractures. Arch Orthop Trauma Surg. 2010;130(10):1289-97.

136. Rammelt S, Zwipp H. Intra-articular Osteotomy for Correction of Malunions and Nonunions of the Tibial Pilon. Foot Ankle Clin. 2016;21(1):63-76.

137. Gan TJ, Ma XK, Li YX, Chen Y, Liu X, Li J, et al. Osteoperiosteal Iliac Autograft Transplantation for Unreconstructable Tibial Plafond After Malunions of Pilon Fractures in Young Patients. Foot Ankle Int. 2024;45(1):33-43.

138. DeCoster TA, Willis MC, Marsh JL, Williams TM, Nepola JV, Dirschl DR, et al. Rank order analysis of tibial plafond fractures: does injury or reduction predict outcome? Foot Ankle Int. 1999;20(1):44-9.

139. Jo S, Tilan J, McAndrew C, Miller AN. Poor Outcomes After Anterior Impaction Pilon Fractures. J Am Acad Orthop Surg. 2022; 30(1):19-26.

140. Willey MC, Compton JT, Marsh JL, Kleweno CP, Agel J, Scott EJ, et al. Weight-Bearing CT Scan After Tibial Pilon Fracture Demonstrates Significant Early Joint-Space Narrowing. JBJS. 2020;102(9):796.

141. Liu X, An J, Zhang H, Li Y, Chen Y, Zhang W. Autologous Osteochondral Graft for Early Posttraumatic Arthritis of Tibiotalar Joints After Comminuted Pilon Fractures in Young Patients. Foot Ankle Int. 2019;41(1):69-78.

142. Bone L, Stegemann P, McNamara K, Seibel R. External fixation of severely comminuted and open tibial pilon fractures. Clin Orthop Relat Res. 1993;(292):101-7.

143. Wu D, Peng C, Ren G, Yuan B, Liu H. Novel anterior curved incision combined with MIPO for Pilon fracture treatment. BMC Musculoskelet Disord. 2020;21(1):176.

144. Tornetta P 3rd, Weiner L, Bergman M, Watnik N, Steuer J, Kelley M, et al. Pilon fractures: treatment with combined internal and external fixation. J Orthop Trauma. 1993;7(6):489-96.

145. 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.
146. Meng YC, Zhou XH. External fixation versus open reduction and internal fixation for tibial pilon fractures: A meta-analysis based on observational studies. Chin J Traumatol. 2016;19(5):278-82.
147. Lu V, Zhang J, Zhou A, Thahir A, Lim JA, Krkovic M. Open versus closed pilon fractures: Comparison of management, outcomes, and complications. Injury. 2022;53(6):2259-67.
148. Boraiah S, Kemp TJ, Erwteman A, Lucas PA, Asprinio DE. Outcome following open reduction and internal fixation of open pilon fractures. J Bone Joint Surg Am. 2010;92(2):346-52.
149. Gardner MJ, Mehta S, Barei DP, Nork SE. Treatment Protocol for Open AO/OTA Type C3 Pilon Fractures With Segmental Bone Loss. J Orthop Trauma. 2008;22(7):451.
150. Haller JM, Githens M, Dunbar R. Intramedullary Nailing for Pilon Nonunions. J Orthop Trauma. 2017;31(11):e395-9.
151. Cinats DJ, Stone T, Viskontas D, Apostle K. Osteonecrosis of the distal tibia after pilon fractures. Foot Ankle Surg. 2020;26(8):895-901.
152. Yeramosu T, Satpathy J, Perdue PW Jr, Toney CB, Torbert JT, Cinats DJ, et al. Risk Factors for Infection and Subsequent Adverse Clinical Results in the Setting of Operatively Treated Pilon Fractures. J Orthop Trauma. 2022;36(8):406-12.
153. Major Extremity Trauma Research Consortium (METRC), O'Toole RV, Joshi M, Carlini AR, Murray CK, Allen LE, et al. Effect of Intrawound Vancomycin Powder in Operatively Treated High-risk Tibia Fractures: A Randomized Clinical Trial. JAMA Surg. 2021;156(5):e207259.
154. Pesante BD, Parry JA. The Effect of Vancomycin and Tobramycin Local Antibiotic Powder on Surgical Site Infections After Open Treatment of Fracture: A Retrospective Propensity-Matched Analysis. J Orthop Trauma. 2024;38(4):177-82.
155. Kellam PJ, Cutshall ZA, Dekeyser GJ, Rothberg DL, Higgins TF, Haller JM, et al. Recovery Curve for Patients With Pilon Fractures Using Patient-Reported Outcome Measurement Information System. Foot Ankle Int. 2023;44(4):317-21.
156. Pollak AN, McCarthy ML, Bess RS, Agel J, Swiontkowski MF. Outcomes after treatment of high-energy tibial plafond fractures. J Bone Joint Surg Am. 2003;85(10):1893-900.
157. Duckworth AD, Jefferies JG, Clement ND, White TO. Type C tibial pilon fractures: short- and long-term outcome following operative intervention. Bone Joint J. 2016;98-B(8):1106-11.
158. van der Vliet QMJ, Ochen Y, McTague MF, Weaver MJ, Hietbrink F, Houwert RM, et al. Long-term outcomes after operative treatment for tibial pilon fractures. OTA Int. 2019;2(4):e043.
159. Mills E, Eyawo O, Lockhart I, Kelly S, Wu P, Ebbert JO. Smoking cessation reduces postoperative complications: a systematic review and meta-analysis. Am J Med. 2011;124(2):144-54.e8.
160. Wukich DK, Joseph A, Ryan M, Ramirez C, Irrgang JJ. Outcomes of ankle fractures in patients with uncomplicated versus complicated diabetes. Foot Ankle Int. 2011;32(2):120-30.
161. Erdmann MW, Court-Brown CM, Quaba AA. A five year review of islanded distally based fasciocutaneous flaps on the lower limb. Br J Plast Surg. 1997;50(6):421-7.
162. Davidovitch RI, Elkhechen RJ, Romo S, Walsh M, Egol KA. Open reduction with internal fixation versus limited internal fixation and external fixation for high grade pilon fractures (OTA type 43C). Foot Ankle Int. 2011;32(10):955-61.
163. Bergin PF, Tarkin IS, Kempton LB, Sagi HC, Hsu J, Archdeacon MT. Optimizing the Host in Fracture Surgery. J Orthop Trauma. 2019;33 Suppl 6:S34-8.
164. De-Las-Heras-Romero J, Lledo-Alvarez AM, Lizaur-Utrilla A, Lopez-Prats FA. Quality of life and prognostic factors after intra-articular tibial pilon fracture. Injury. 2017;48(6):1258-63.