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REVIEW ARTICLE

High-energy tibial pilon fractures: an instructional review

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Abstract

High-energy tibial pilon fractures continue to represent a significant challenge to the treating orthopaedic surgeon. Pre-operative evaluation includes a careful clinical assessment of the associated soft tissue injury, which frequently dictates surgical management. Staged surgical reconstruction remains the standard treatment protocol at most trauma centres. This includes application of a temporary spanning external fixator for approximately one to four weeks, followed by open reduction and internal fixation once the surrounding soft tissues are amendable. Despite careful soft tissue management protocols, the risk of wound complications continues to be relatively high compared to other orthopaedic trauma procedures. The functional long-term outcomes of these injuries remain limited, and recent data has emphasised that the majority of patients do not regain their pre-operative work status. In addition, the health-related quality of life scores fare poorly when compared to other orthopaedic and non-orthopaedic patient populations, and many patients develop post-traumatic arthritis within the tibiotalar joint. It has been shown that the quality of fracture reduction may significantly correlate with the long-term functional outcomes. While the orthopaedic community has come a long way with regard to safe management of high-energy tibial pilon fractures, the clinical outcomes continue to remain limited. In particular, the persistently high rates of wound complications and the limited functional long-term outcomes leave significant room for improvement. Future investigators may focus on further innovations to minimise the risk of wound complications. The surgical team may emphasise the quality of fracture reduction as an important treatment goal.

Keywords Distal tibia · Pilon · Plafond · Fracture · Soft tissue injury

Introduction

Fractures to the tibial plafond, or pilon fractures, represent approximately 5–7% of all tibia fractures [1]. They are frequently the result of a fall from height or a motor vehicle collision creating an axial loading injury. The osseous involvement may include various patterns of articular impaction, comminution, and displacement. Significant comminution and deformity are typically encountered with the distal tibial metaphysis and the distal portion of the tibial shaft. The dissipating high-energy forces commonly result in a significant injury to the surrounding soft tissues. Approximately 30% of high-energy tibial plafond fractures present as open fractures [2, 3].

High-energy fractures of the tibial plafond continue to represent a significant challenge to the treating orthopaedic surgeon. Despite significant advances, the risk of wound complications remains relatively high compared to other orthopaedic trauma procedures, and the functional long-term outcomes are frequently limited [4–6]. Given the relatively high risk of wound complications, appropriate soft tissue management plays a crucial role in the surgical treatment. The goal of this article is to provide a comprehensive review of the injury assessment, soft tissue management, surgical treatment options, patient outcomes, and future perspectives.

Injury assessment

Pathophysiology

Low-energy tibial plafond fractures are commonly the result of rotational forces with less severe soft tissue injury. In contrast, high-energy tibial plafond fractures are usually caused by an axial loading injury, where the talus impacts onto the

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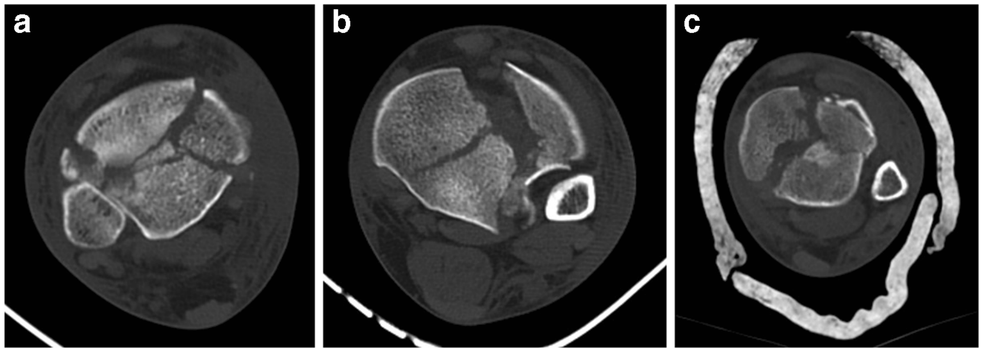

Fig. 1 **a**–**c** Axial CT cuts at the level of the tibial plafond depicting different injury patterns with consistent presentation of an anterolateral fragment, anteromedial fragment and posterolateral fragment

distal tibial joint surface creating a severe osseous and soft tissue injury.

The articular involvement may include different patterns with various degrees of articular impaction and comminution. However, the majority of pilon fractures shows a fairly consistent articular fracture pattern with the presence of an anterolateral, anteromedial, and posterolateral fragment (Fig. 1a–c) [7]. Significant comminution and deformity within the distal tibial metaphysis and shaft are commonly observed. It is important to distinguish between primary valgus versus varus deformities as these have important implication for the subsequent fixation construct and plate position. The presence of a fractured fibula is indicative of a higher-energy injury pattern and valgus load, while the absence of fibular fracture may indicate a varus load.

The distal tibia has a relatively thin soft tissue envelope, which is prone to high-energy forces. Therefore, high-energy tibial plafond fractures are associated with significant soft tissue compromise. Clinical markers of the soft tissue injury include swelling, ecchymosis, degloving injuries, clear fluid-filled fracture blisters, blood-filled fracture blisters, compartment syndrome, neurovascular injuries, and open fractures (Fig. 2a–e) [8]. It is crucially important for the treating surgeon to recognise and document the associated soft tissue injury as appropriate soft tissue management plays a key role in the surgical treatment.

Initial evaluation

In trauma patients, initial clinical assessment should first involve evaluation for life-threatening injuries, such as airway obstruction, respiratory failure, haemorrhagic shock, or brain injuries, according to the Advanced Trauma Life Support guidelines [9]. The history taking should also particularly identify comorbidities that are widely known to be associated with the risk of surgical site complications, such as diabetes, peripheral neuropathy, peripheral vascular disease, osteoporosis, malnutrition, smoking, and alcoholism, since these need to be addressed appropriately during the perioperative period [10–13]. The orthopaedic examination of the affected extremity entails a thorough assessment of the soft tissue injury and

Fig. 2 Soft tissue injury in patient with right pilon fracture (**a**) depicting the skin swelling over the lateral side (**b**), ecchymosis and blood-filled fracture blisters over the medial side (**c**). Patient with blood-filled fracture blisters as an indicator of severe soft tissue injury (**d**). Clear fluid-filled fracture blisters indicating a less severe internal injury (**e**)

Fig. 3 Patient with pilon fracture after approximately 2 weeks in a spanning external fixator. Skin with positive wrinkle sign as an indicator of decreased swelling

neurovascular status of the limb. Important data points include presence and degree of swelling, fracture blisters, degloving injuries, open wounds, and neurovascular deficits [8]. Repeat clinical examinations are vital since the soft tissue compromise will continue to evolve after the initial injury.

The initial radiographic evaluation includes standard radiographs of the knee, tibia/fibula, ankle, and foot. Computed tomography (CT) scans with fine cuts, sagittal, and coronal reconstructions allow for appropriate assessment of the articular injury pattern as well as identification of associated injuries, such as injuries to the talar neck, talar body, and osteochondral talus lesions. However, it is recommended to obtain the CT scans after preliminary reduction of the fracture (and possible application of an external fixator) in order to obtain the best possible depiction of the articular damage [7, 14]. In particular, the most distal axial cuts of the tibial plafond provide essential information for delineating the articular injury pattern and planning of the surgical approach and reconstruction.

Classification

The original classification of pilon fractures by Rüedi and Allgöwer [15] entailed three fracture types with increasing severity including cleavage fracture of distal tibia without major dislocation of articular surface (type 1), significant fracture dislocation of joint surface without comminution (type 2), and impaction and comminution of distal tibia

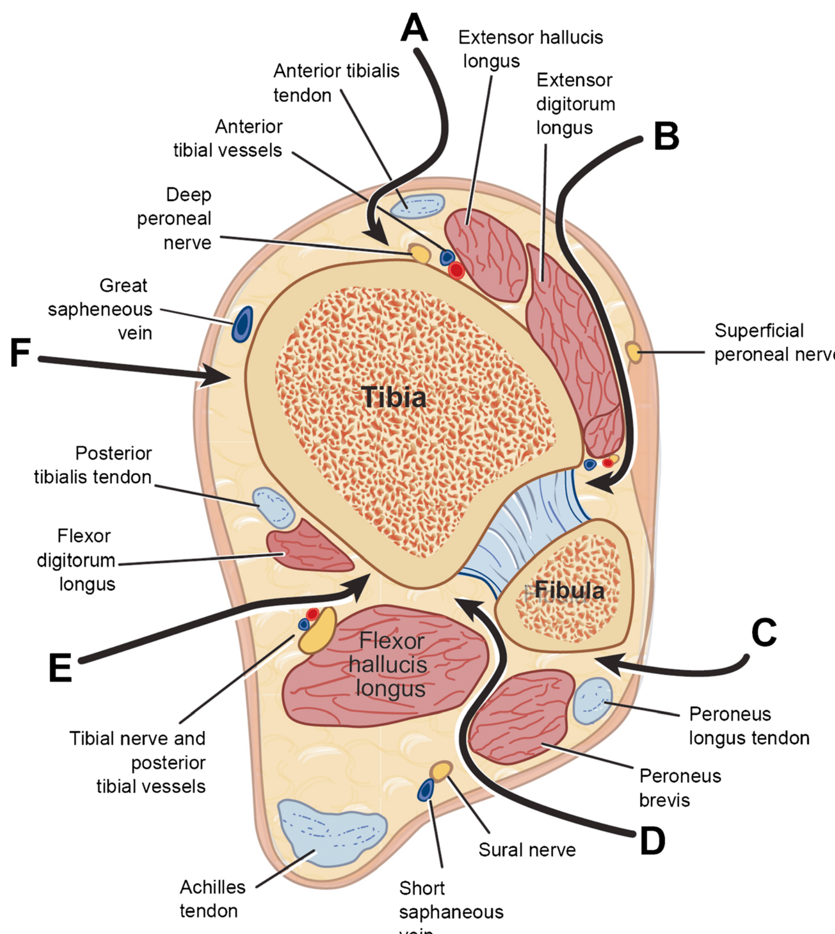

Fig. 4 Schematic drawing of axial cut at the level of the tibial plafond depicting the intervals for the standard surgical approaches including anteromedial and extensile anteromedial (A), anterolateral (B), posterolateral fibula (C), posterolateral tibia (D), posteromedial (E), and direct medial (F)

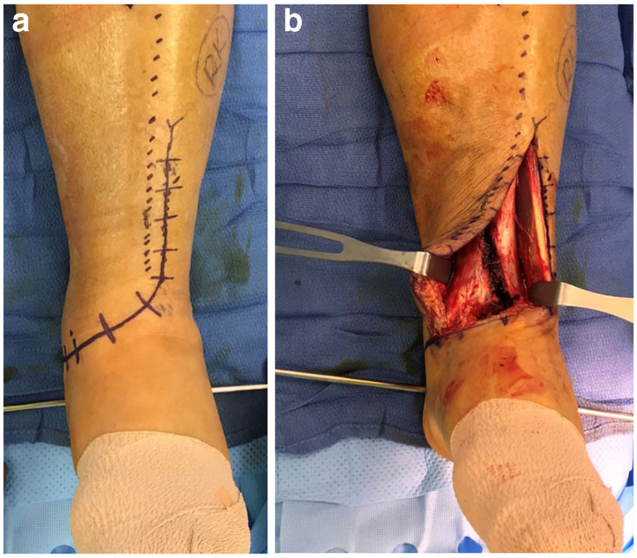

Fig. 5 Extensile anteromedial approach to left pilon fracture with marked incision (solid line) just lateral to the anterior tibial crest (dotted line) (**a**). Deep surgical dissection with exposure of medial and anterior plafond. Tibialis anterior tendon retracted laterally with the tendon sheath carefully protected (**b**)

(type 3). The more recent Arbeitsgemeinschaft für Osteosynthesefragen (AO)/OTA classification system divides pilon fractures into three main groups including extraarticular (43-A), partial articular (43-B), and complete articular (43-C) [16]. Limitations of these traditional classifications include a purely radiographic basis that does not delineate the anatomy of the articular surface and moderate inter- and intra-observer reliability [17, 18]. Newer classification systems based on CT imaging have been suggested to be more prognostic, reliable, and reproducible [7, 19]. However, the AO/OTA classification system remains the most widely used classification system for pilon fractures.

Treatment

Evolution of surgical treatment

Historically, pilon fractures were viewed as "non-reconstructable" and poor late outcomes were typically encountered with non-operative treatment [20]. In 1969, Rüedi and Allgöwer [15] reported their pioneering experience of open reduction and internal fixation (ORIF) using plating technology with the four principle steps of (1) reconstruction of the correct fibular length, (2) reconstruction of the articular surface, (3) filling of metaphyseal void with bone graft, and (4) internal plate fixation. In a series of 84 patients with an average follow-up of 50 months, they recorded that 74% of patients were free of pain, 90% had returned to their previous occupation, and only a 5% acquired a deep infection [15].

These favourable results were not reproduced in subsequent series from the USA [10, 21]. In 52 pilon fractures treated with early ORIF, McFerran et al. [21] encountered wound complications in more than one third of their patients. Similarly, Teeny et al. [10] reported a deep infection rate of approximately 37% in 60 patients with pilon fractures treated with early ORIF. The discrepancy between these devastating results from the USA and the favourable outcomes reported by Rüedi and Allgöwer [15] was likely due to differences in the patient populations. Thus, it was assumed that the higher complication rates observed within the US series were due to higher-energy mechanisms with relatively large numbers of polytrauma patients, motor vehicle collisions, and open fractures [10, 21]. In contrast, Rüedi and Allgöwer [15] seemingly reported on lower-energy traumas, with approximately 70% skiing injuries. Increased awareness of soft tissue vulnerability led to the exploration of alternative treatment strategies. Subsequently, external fixation constructs were attempted as

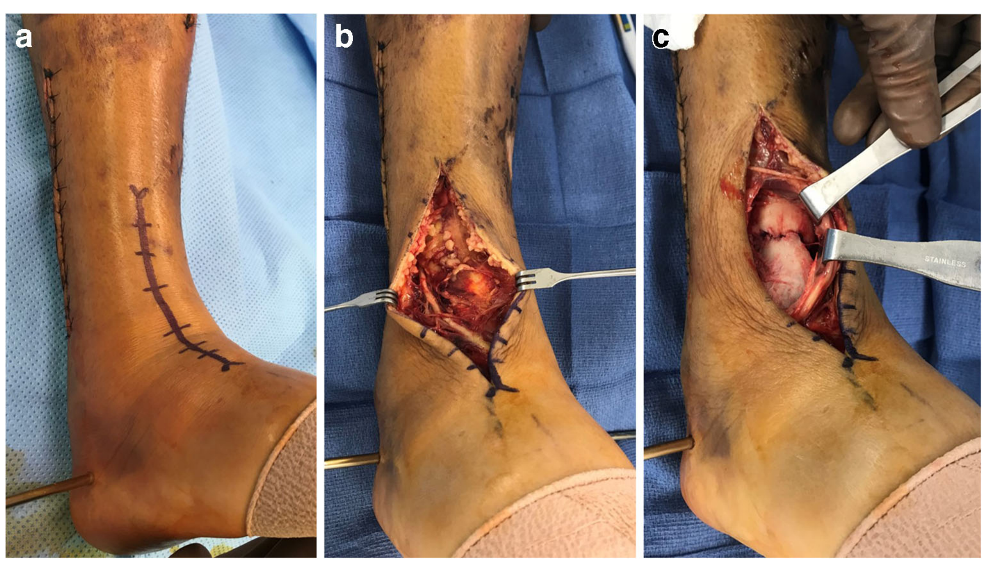

Fig. 6 Anterolateral approach to right tibial plafond with incision lateral to anterior muscle compartment (**a**). Deep dissection encounters the superficial peroneal nerve (**b**). Lateral retraction of anterior compartment allows for exposure of anterior tibial plafond (**c**)

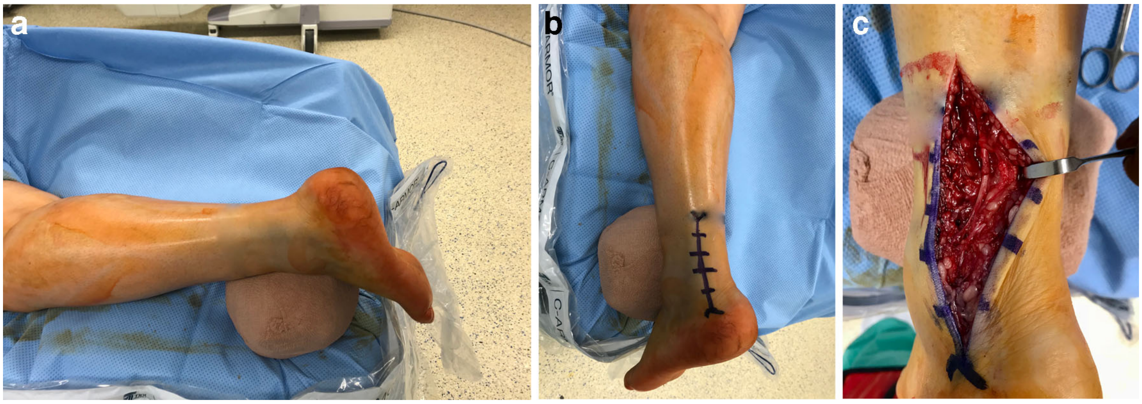

Fig. 7 Posterolateral approach to the left tibial plafond in the prone position (**a**). Incision placed approximately halfway between Achilles tendon and posterior edge of fibula (**b**). Deep surgical dissection with exposure and careful protection of sural nerve (**c**)

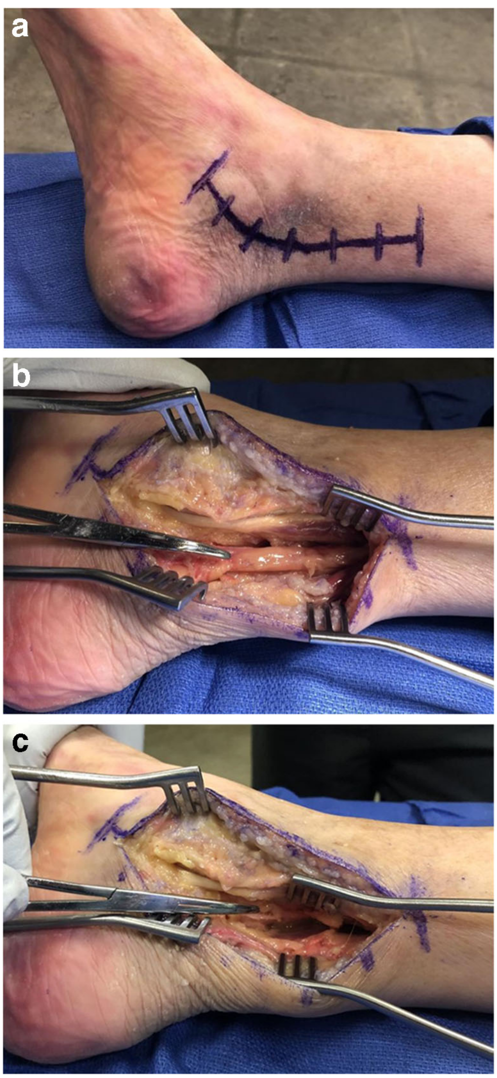

Fig. 8 Posteromedial incision depicted in cadaveric model (**a**). Surgical clamp pointing onto neurovascular bundle just posterior to PT tendon (**b**). Interval between the PT tendon and the neurovascular bundle allowing for visualisation of posteromedial tibial plafond (**c**)

definitive treatment [22, 23]. These attempts included the use of plain as well as circular external fixators, which sometimes were combined with open fibular reconstruction or percutaneous screw fixation of the articular surface. While this management strategy lowered the rate of soft tissue complications, it also resulted in high rates of pin site infections, non-union, malunion, and post-traumatic arthritis [22, 23].

In 1999, staged surgical reconstruction was popularised as a viable treatment method [24, 25]. This approach includes temporary application of an ankle spanning external fixator with or without ORIF of the associated fibula fracture at the time of injury. This is followed by an interim phase of approximately 1–4 weeks, which allows for resolution of soft tissue injury. Once indicators of decreased swelling, such as re-epithelialisation of fracture blisters and appearance of skin wrinkles, occur, formal ORIF of the tibial plafond can be performed in a safe fashion (Fig. 3). As relatively low soft tissue complication rates have been reported with staged surgical reconstruction, this method has become the standard treatment at most trauma centres [24–26].

Surgical approaches

Various approaches have been described for the management of pilon fractures [27]. The most commonly described approaches include anterolateral, anteromedial, extensile anteromedial approach, direct lateral, direct medial, posterolateral tibia, posterolateral fibula, and posteromedial (Fig. 4). The surgical approaches should be tailored towards the individual fracture pattern and the associated soft tissue injury.

The anteromedial approach is the classic approach that was popularised by the AO [20]. The incision starts 15 mm distal to the tip of the medial malleolus and curves anteromedially over the medial portion of the tibial plafond and along the subcutaneous border of the tibia. The deep dissection then stays medial to the tibialis anterior tendon. The approach allows access to the medial malleolus and the medial portion of the tibial plafond. However, the lateral portion of the tibial

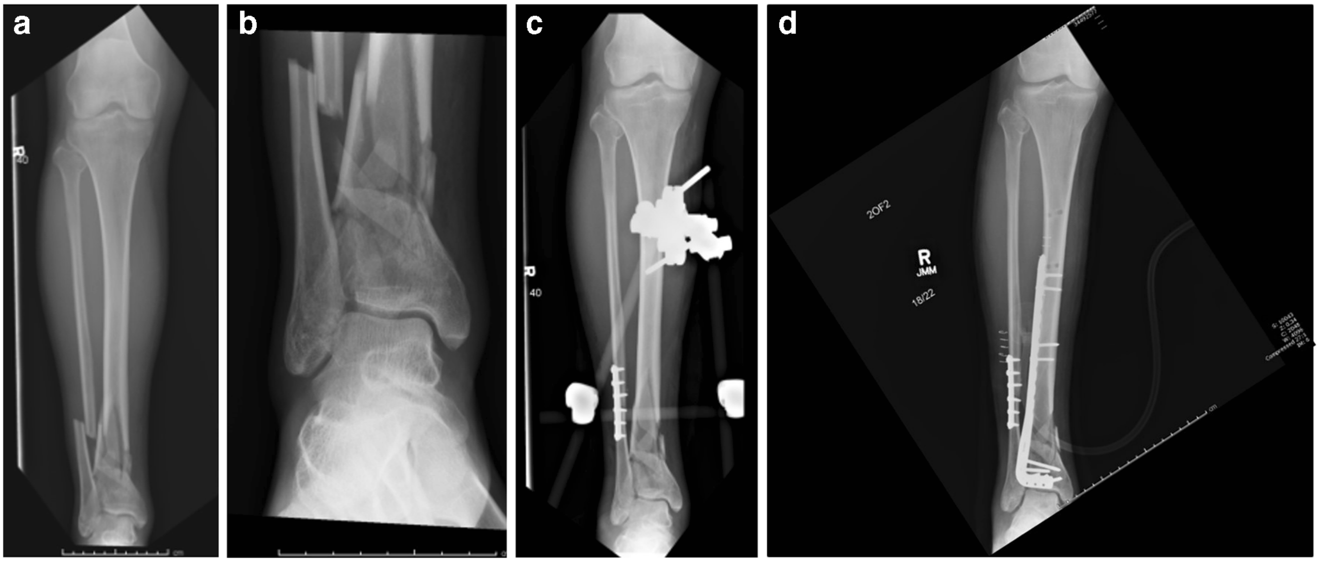

Fig. 9 Right pilon fracture with associated fibula fracture and primary valgus deformity (**a**, **b**). Temporary application of spanning external fixator and immediate ORIF of fibula (**c**). Definitive ORIF in a staged fashion with anterolateral plate bridging metaphyseal comminution (**d**)

plafond cannot be accessed, and the relatively thin flap created over the medial side may lead to hardware prominence and wound breakdown. Given these downsides, we typically prefer the extensile anteromedial approach [28]. In this approach, the proximal part of the incision is carried from proximal to distal approximately 1 cm lateral to the tibial crest. At the level of the joint line, the incision is curved medially in an approximately 70° angle in order to end 1 cm distal to the tip of the medial malleolus. The anterior muscle compartment with the neurovascular bundle can be elevated from medial to lateral, which allows for exposure of the entire anterior and medial portion of the tibial plafond (Fig. 5a, b).

The anterolateral approach includes a vertical incision lateral to the anterior muscle compartment (Fig. 6a–c). Distally, the incision is carried along the fourth ray of the foot and approximately 4 cm distal to the ankle joint. The superficial peroneal nerve is encountered within the proximal aspect of the incision and must be protected. The anterior muscle compartment can be elevated from lateral to medial, allowing for exposure of the entire anterior tibial plafond and appropriate soft tissue coverage over the plate. The lateral approach uses an incision over the fibula, and the superficial peroneal nerve is encountered [29]. The deep dissection is then carried anteriorly over the fibula, and the anterior muscle compartment

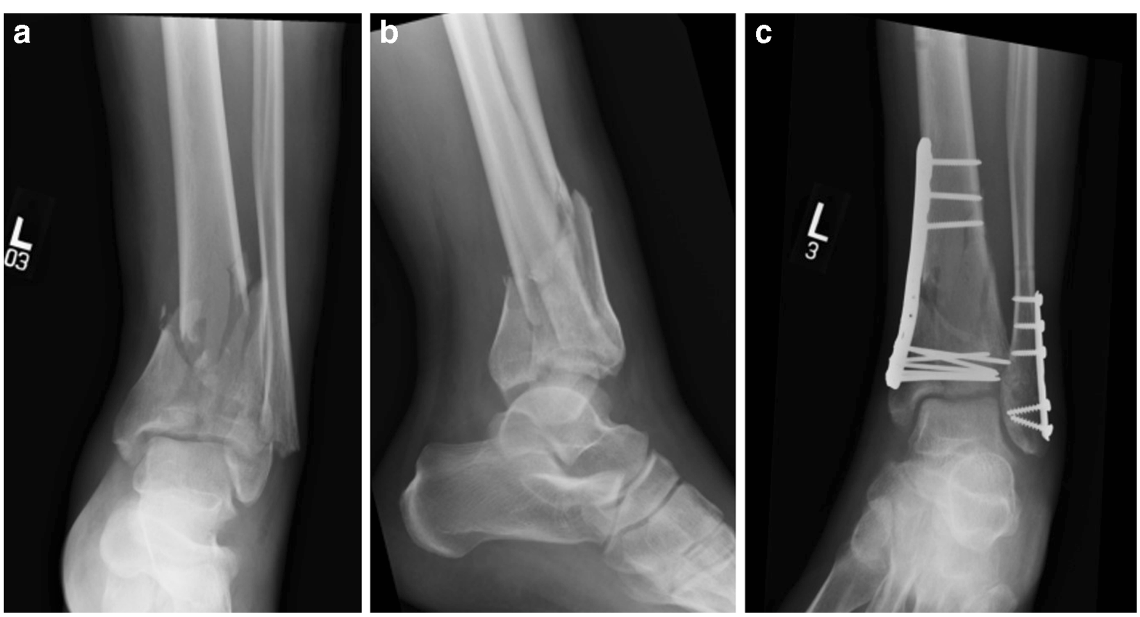

Fig. 10 Left pilon fracture with primary varus deformity (**a**, **b**). Staged surgical reconstruction with ORIF of fibula and medial-based plate fixation of tibial plafond (**c**)

can be elevated from lateral to medial, similar to the anterolateral approach. This approach allows for exposure and fixation of both the entire anterior tibial plafond and the fibula.

The posterolateral approach can be performed with the patient in either the lateral or prone position (Fig. 7a–c). The incision is longitudinal approximately midway between the Achilles tendon and the fibula. The sural nerve is encountered and must be protected. The deep surgical dissection uses the interval between the flexor hallucis longus and the peroneals. The deep posterior muscle compartment is then elevated from lateral to medial, so the posterior tibial plafond can be accessed. Of note, the fibula can be accessed through the same incision. If only a direct access to the fibula is desired, the deep dissection can be carried out just anterior to the peroneal tendons.

The posteromedial approach employs an incision between the Achilles tendon and the medial malleolus (Fig. 8a–c). The deep dissection can go anterior to the posterior tibial tendon or any of the intervals between the tendons of the deep posterior muscle compartment. Because the neurovascular bundle needs to be carefully protected, the exposure is limited to a relatively small area of the posteromedial tibial plafond. Indications include the need to access to a posteromedial fragment or entrapment of the neurovascular bundle or tendons. In these cases, the posteromedial approach is typically combined with other surgical approaches.

In many instances, multiple approaches are used in combination, and studies have shown that the use of dual incisions is typically safe with regard to wound complications [30]. The traditional AO recommendation was that a minimum 7-cm skin bridge between two incisions should be maintained [31]. However, in their case series of 46 tibial plafond fractures, Howard et al. [30] reported that their average skin bridge was 5.9 cm (range 3.0 to 10.9 cm) and 83% of these skin bridges were less than 7 cm. In particular, the combination of a posterolateral approach with an anterolateral approach resulted in relatively small skin bridges. The authors encountered an overall satisfactory soft tissue complication rate of 9% and concluded that, with appropriate soft tissue management and respect of the blood supply to the wound, skin bridges smaller than 7 cm can be tolerated [30].

Definitive ORIF

The goal of ORIF is to achieve an anatomic reduction of the articular surface, restoration of length alignment and rotation, and stable fixation to allow for early mobilisation. Surgeons

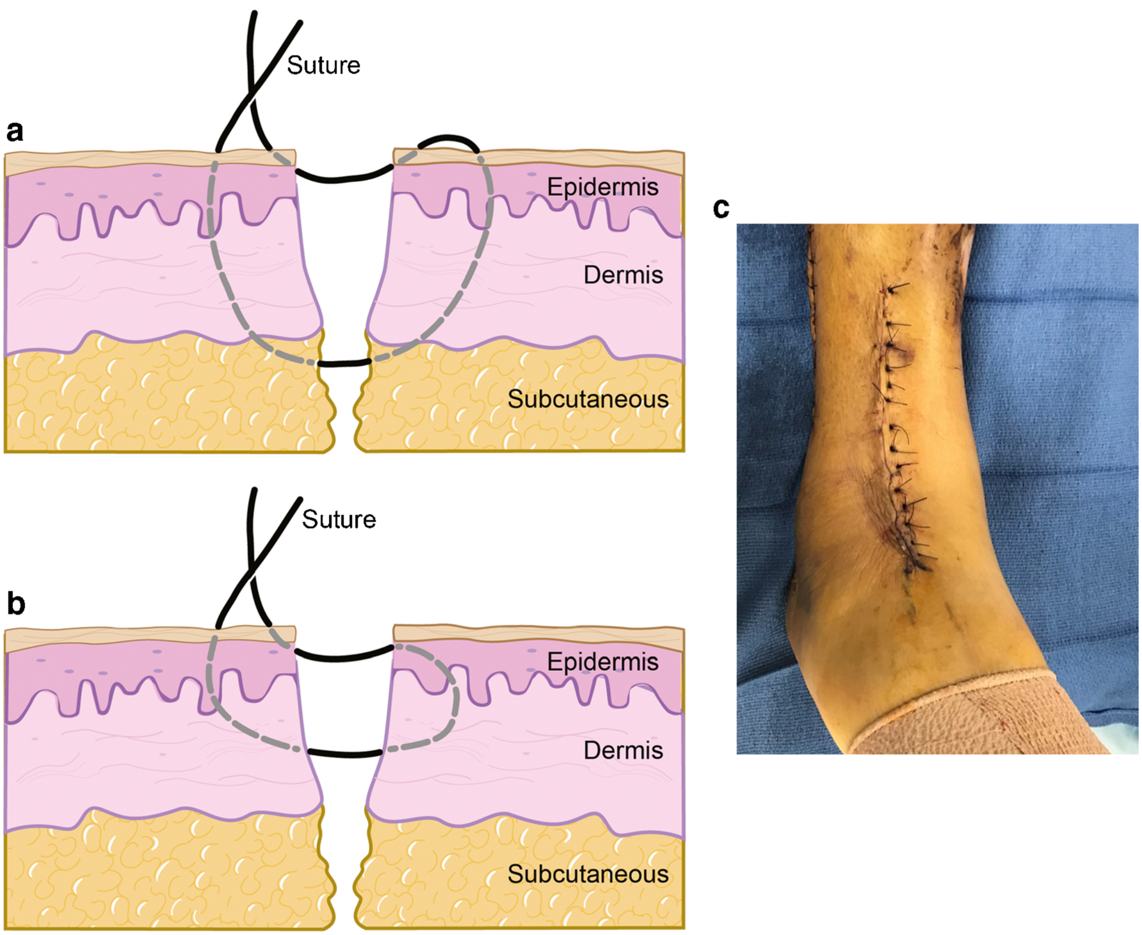

Fig. 11 Schematic drawings of Donati vertical mattress suture (**a**) and Allgöwer–Donati suture (**b**, **c**)

Fig. 12 Incisional negative pressure wound therapy (iNPWT) applied over a closed wound with the goal of minimising the risk of wound complications

choose from different surgical approaches, various implant constructs, and combinations thereof [32–35]. Therefore, numerous options for ORIF of the tibial plafond are available for use based on individual fracture pattern and surgeon's preference. Still, the four principle steps of (1) fibular reconstruction, (2) reconstruction of the articular surface, (3) bone grafting, and (4) plate fixation as outlined by Rüedi and Allgöwer [15] remain undisputed and play a key role in the surgical planning.

The pathoanatomy of the articular surface typically dictates the choice of the surgical approach. The main articular fracture line must be accessed in order to book the fracture open anteriorly and to access the area of central impaction [36]. Anterior access to the tibial plafond is essential in the majority of high-energy pilon fractures. Our institutional preference is to use the extensile anteromedial or anterolateral approach to accomplish this goal. In most fracture patterns, the surgeons aim to reduce the articular fragments from posterior to anterior using the posterolateral fragment as a constant fragment. Establishing the posterolateral fragment as a constant fragment can be achieved in different ways. Surgical reconstruction of the fibula may result in reduction of the posterolateral fragment through ligamentotaxis. Additionally, the posterolateral fragment may be accessed through the anterior approach and can be reduced to the shaft. Finally, a posterolateral approach may allow for a direct reduction of this fragment and can convert a C-type pilon fracture into a B-type [37].

Following surgical reconstruction of the articular surface, the articular block is connected to the proximal shaft fragment using low-profile locking or non-locking plates. Generally, injuries that present with a primary valgus deformity require an anterolateral buttress (Fig. 9a–d), whereas primary varus deformities require a medial buttress (Fig. 10a–c). While multiple plating lines from different manufacturers are available, most pilon systems provide precontoured anterolateral and medial plate options. In many complex tibial plafond fractures, a combination of plates becomes the preferred fixation choice.

Controversy still exists regarding fibula management. Early reports of the staged treatment protocol suggested immediate application of an external fixator along with surgical fixation of the fibula [24, 25]. However, many surgeons currently avoid fixing the fibula immediately. A potential downside of immediate fibula fixation includes that even a subtle malreduction of the fibula may significantly hinder the subsequent surgical reduction of the tibial plafond. In addition, application of the external fixator frequently precedes the CT scan, so the strategy for the surgical reconstruction may not be fully defined at this time point. Thus, the fibula incision may potentially interfere with future surgical incisions that are deemed necessary for the reconstruction of the tibial plafond. Finally, it remains a subject of an ongoing debate if all fibula fractures associated with high-energy tibial plafond fractures actually require ORIF. Recently, Kurylo et al. [38] reported a series of 111 patients with high-energy tibial plafond fractures. The authors recorded that fibula fixation did not improve postoperative alignment but was associated with a higher rate of hardware removal. The authors concluded that, in pilon fractures, surgical fixation of the associated fibula fracture may be a helpful adjunct in achieving an anatomic reduction of the tibial plafond, but not all patients benefit from this intervention [38]. Still, others maintain that stabilisation of a fractured fibula is important in decreasing distal tibial malunion and post-traumatic ankle arthrosis [39]. At our institution, most fibula fractures are addressed during the staged definitive reconstruction of the tibial plafond. Choice between ORIF of the fibula, percutaneous intramedullary fixation, or close treatment depends on several factors, such as the fracture pattern, associated soft injury, patient comorbidities, and the surgical approaches used for addressing the tibial plafond.

Minimising the risk of wound complications

Wound complications represent a significant challenge in the treatment of high-energy tibial plafond fractures [4]. Besides appropriate utilisation of staged treatment protocols, thoughtful intraoperative soft tissue handling plays an important role

Fig. 13 Severely comminuted tibial plafond with significant soft tissue injury (**a**, **b**). Definitive fixation with external ring fixator as an alternative treatment option (**c**, **d**). Fracture consolidation at 1-year follow-up (**e**). With friendly permission from Anton Y. Plakseychuk, MD, PhD

in minimising wound complications. Experimental and clinical data suggests improved wound oxygenation with the Allgöwer modification of the Donati vertical mattress suture, i.e. Allgöwer–Donati suture (Fig. 11a–c) [40, 41]. Further recent advances include the use of incisional negative pressure wound therapy (iNPWT) [4]. These can be applied onto the surgical wound immediately following wound closure under sterile conditions (Fig. 12). Contemporary systems provide portable pumps that allow for continuation of iNPWT after discharge. In a prospective multicentre study of 263 high-risk lower extremity fractures, Stannard et al. [4] reported a decreased incidence of wound dehiscence and infections with the use of iNPWT. Further surgical measures with the potential to minimise the risk of surgical site complications include the intraoperative application of vancomycin powder; however, the efficacy of this treatment is currently being investigated in ongoing multicentre studies [42, 43].

Peri-operative medical management also plays a crucial role in minimising surgical site complications [13]. In particular, medical problems that have been associated with the increased risk of surgical site complications, such as diabetes, peripheral neuropathy, peripheral vascular disease, osteoporosis, malnutrition, smoking, and alcoholism, need to be addressed during the peri-operative period [10–13]. Reasonable perioperative medical interventions may include nutritional supplementation, blood sugar control, stenting of occluded vessels, or nicotine counselling. Current investigations are underway to further determine the efficacy of peri-operative oxygen supplementation [44, 45].

Alternative treatment options

Several alternative treatment options have been proposed for specific indications. Minimally invasive plating techniques have been suggested for pilon fractures with the goal to minimise wound complications but are limited to fracture patterns with minimal joint involvement which do not require direct access of the articular surface [46–48]. Circular external fixation may represent a viable option for select patients with extensive open fractures, major soft tissue injury, or significant comorbidities, such as diabetes or immune deficiency [49, 50]. Circular frames also provide a biomechanically stable construct while minimising the need for extensive surgical incisions. However, a significant shortcoming is the inability to obtain a direct anatomic reduction of the articular surface (Fig. 13a–e). Vidyadhara and Rao [50] reported on 21 consecutive patients, who were treated with an Ilizarov external fixator for their complex tibial plafond fractures. These authors reported that all fractures united and only one patient reported a poor functional outcome. Primary arthrodesis has been suggested as an option for severely comminuted, non-reconstructable tibial plafond fractures [51, 52]. Since some arthrodesis techniques allow for a posterior approach, the frequently traumatised anterior soft tissues can be avoided. While satisfactory outcomes have been reported, it must be emphasised that this concept should be strictly reserved for a very select patient population with severely comminuted, non-reconstructable plafond fractures or with loss of bone and cartilage following open fractures.

Functional long-term outcomes

Traditionally, the functional long-term outcomes of high-energy tibial plafond fractures have been reported as poor. Pollak et al. [5] recorded that at more than three years of follow-up, pilon fracture patients had significantly lower health-related quality of life (HRQoL) scores than age- and gender-matched norms and also lower scores than patients with severe medical problems such as myocardial infarction, diabetes, and acquired immunodeficiency syndrome (AIDS) [5]. Recent studies have also confirmed this observation at long-term follow-up. The HRQoL scores of patients with pilon fractures remain severely compromised and significantly below the general population [53–55]. Years after the injury, many patients continue to struggle with pain and limited mobility [5, 55–57]. Additionally, many patients are unable to return to work after their injury [5, 6, 55, 56]. Volgas et al. [6] reported that at an average follow-up of 12 months, less than 15% of all blue-collar workers had returned to work, emphasising the significant socioeconomic burden of this injury. The development of post-traumatic arthritis represents another limiting factor for long-term outcome [54, 58, 59]. It has been reported that in type C3 pilon fractures, the rate of post-traumatic arthritis at two years follow-up may be greater than 50% [59]. Moreover, the presence of post-traumatic arthritis has been correlated with poor HRQoL scores [54].

Many of the factors determining the functional outcomes seem to be non-modifiable, such as injury- and patient-related factors. However, studies have shown that the quality of fracture reduction significantly correlates with the functional long-term outcomes and the HRQoL scores [53, 54, 58]. Thus, the quality of fracture reduction represents an important modifiable risk factor and treatment goal that the surgical team can control.

Conclusions

High-energy pilon fractures are commonly associated with significant soft tissue damage, and staged surgical reconstruction is frequently necessary in order to minimise surgical site complications. Meticulous soft tissue management remains a crucial part of the surgical procedure. The role of various medical and surgical modifications in minimising the risk of surgical site complications, such as nutritional optimisation, supplemental oxygen, local antibiotics, and iNPWT, requires further investigations. Despite staged treatment protocols, appropriate soft tissue management, and modern technology, the overall functional long-term outcomes remain limited. The surgical team should emphasise the quality of fracture reduction as a modifiable risk factor and an important treatment goal since it correlates significantly with the functional long-term outcomes.

Compliance with ethical standards

Conflict of interest BAZ has received research grants from DePuySynthes, Inc., KCI Inc., and the Orthopaedic Trauma Association. BAZ has received speaker honoraria from AO Trauma North America. BAZ has received an educational grant from Smith & Nephew Inc. KHD and SSO declare that they have no conflict of interest.

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