



Current Concepts in Talar Neck Fracture Management

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Abstract

Purpose of the review Talar neck fractures are a rare but potentially devastating injury, which require a comprehensive understanding of the unique osteology, vasculature, and surrounding anatomy to recognize pathology and treat correctly. The purpose of this article is to describe both classic and current literature to better understand the evolution of talar neck fracture management.

Recent findings Urgent reduction of displaced fractures and dislocations remains the standard of care to protect the soft tissue envelope and neurovascular structures. Delayed definitive fixation has proven to be safe. CT is the imaging modality of choice to fully identify the fracture pattern and associated injuries. Anatomic reduction and restoration of the peritalar articular surfaces are the pillars of talar neck fracture treatment. Dual incision approach with plate and screw fixation has become the modern surgical strategy of choice to accomplish these goals. Although complications such as osteonecrosis (ON) and posttraumatic arthritis (PTA) can still occur at high rates, treatment should be dictated by patient symptoms.

Summary Talar neck fractures pose treatment challenges with both initial injury and potential sequelae. Future research will determine whether modern treatment algorithms will decrease complication rate and improve patient outcome.

Keywords Talar neck fracture · Treatment · Complications · Outcomes · Review

Introduction

Talar neck fractures have traditionally been quoted to account of less than 1% of all fractures [1]. Due to the rarity of these injuries, most of the literature published on treatment, complications, and outcomes has been limited to case series, preventing the ability to draw definitive conclusions [1–10]. However, there have been several important paradigm shifts from traditional dogma in areas, such as surgical timing, approach, and fixation methods. Within the past 5 years, there have been a number of review articles which have helped to show how treatment has evolved [11•, 12•, 13•, 14•, 15•, 16•, 17]. This article will focus on the current understanding of the anatomy, classification, imaging, and surgical treatment of talar neck fractures, with insight from the senior author on

his preferred techniques. The latest evidence on complications and outcomes of these injuries will also be reviewed.

Anatomy

The talus is broken up into three regions: head, neck, and body. The talus has no muscular attachments and more than half of the talus is covered by articular cartilage. As a result, the talus serves as the key stone to multiple complex articulations with the tibia superiorly (tibiotalar joint), calcaneus inferiorly (subtalar joint), and the navicular anteriorly (talonavicular joint). The medial and lateral extensions of the superior talar articular surface also articulate with their respective ankle malleoli. The superior portion of lateral malleolus also articulates with the lateral process of the talus.

The talar neck is angled medially (10–44°) and plantarly (5–50°) with respect to the body [18]. The neck is relatively devoid of articular cartilage. Classically, the importance of the neck not only lies in that it is the structural connection between the head and body, but that it is also the conduit for the talar body's retrograde blood supply [19, 20]. However, more

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recent gadolinium-enhanced MRI cadaveric studies have demonstrated a more robust antegrade blood supply, which may account for the fact that not every talar neck fracture progresses to osteonecrosis (ON) [21, 22].

The osteology of the talar neck is also unique, as it has less trabecular bone than the head or body, and the trabeculae are in a different orientation than the body [23]. Although the trabecular bone in the talar body is in the same direction as body weight transmission, transferring body weight from the plafond to the foot, there is an abrupt change in direction of the trabeculae at junction of the talar body and neck, making the talar neck susceptible to fracture [23]. The classically described mechanism of talar neck fracture is forced ankle dorsiflexion combined with axial loading, resulting in the talar neck impacting the anterior plafond edge [2, 3, 5, 18, 24]. However, most injuries also involve a rotational component (hindfoot supination) causing the talar neck to impact against the medial malleolus. This results dorsomedial talar neck comminution and a predilection of the talar neck to fall into varus and extension malalignment. Medial malleolar fractures can also occur in up to 28% of patients [2, 4, 5, 25, 26].

Classification and imaging

The value of any classification system is based on its ability to guide treatment or provide prognostic information. The Hawkins classification is the most widely cited for describing talar neck fractures, as higher severity types have been classically linked with increasing likelihood of developing ON [2]. Type I fractures are nondisplaced. Types II and III are fractures which involve subluxation or dislocation of the subtalar and tibiotalar joints respectively. The Hawkins classification system was further expanded by Canale and Kelly to include type IV fractures with dislocation of the talonavicular joint [5]. Recent systematic reviews have summarized the incidence of each fracture type and the correlation between fracture type and the development of ON (Table 1) [11••, 12••, 16••]. Hawkins type II fractures have also been subdivided to increase predictability of the classification [27]. Type IIa fractures indicate a subluxation of the subtalar joint, whereas type IIb indicate a complete dislocation. In a retrospective analysis of 65 talar neck fractures over the course of 10 years, no type IIa fractures developed ON, while 25% of type IIb fractures developed this complication [27].

Table 1 Hawkins classification, incidence, and rate of osteonecrosis

Hawkins type	Associated joint subluxation/dislocation	Incidence	Rate of osteonecrosis
1	n/a	21%	0–5.7%
2	Subtalar	43%	15.9–20.7%
3	Subtalar, Tibiotalar	31%	38.9–44.8%
4	Subtalar, Tibiotalar, Talonavicular	5%	12.1–55%

In order to appropriately classify a talar neck injury, appropriate imaging must be taken. Anteroposterior (AP), oblique, and lateral (LAT) radiographs of both the ankle and foot should be taken to initially assess the extent of the injury. The talar neck itself can also be better visualized radiographically by obtaining tangential views of the foot with the beam angled 75° from the horizontal, the ankle in maximal plantar flexion, and the foot in varying degrees of eversion, classically described at 15° by Canale and Kelly [5, 28]. Delineating the subtleties of talar neck fractures have drastically improved with the use of computed tomography (CT) scans. CT improves recognition of fractures patterns and associated pathology that can be easily missed on radiographs [29–32]. Due to the complex peritalar anatomy, even minimal talar neck displacement can result in subtle incongruity of its associated articulations [32]. Radiographic “undisplaced” talar neck fractures can be misclassified as type I without the use of CT scan. Biomechanical data has shown that as a little as 2 mm of displacement leads to altered subtalar joint contact pressures, which theoretically can predispose the joint to posttraumatic arthrosis [33]. As a result, there has been a further modification of the Hawkins-Canale classification to account for displacement that can only be identified on CT [31]. In fact, CT scan has shown that the vast majority of talar neck injuries cannot be described by the Hawkins classification [31, 32]. CT scan has further demonstrated that isolated talar neck fractures are rare, the majority of “radiographic” talar neck fractures were actually talar body fractures that extend to the neck, and additional information is gained in 93% of cases [32].

The senior author also finds it helpful to obtain three-dimensional (3-D) CT reconstructions to fully comprehend the spatial pattern of the fracture and associated subluxation or dislocations (Figs. 1, 2, and 6). However, it is important to carefully scrutinize the coronal, sagittal, and axial images, as 3-D reconstructions are limited by the software used and volume rendering. The combination of conventional two-dimensional (2-D) and 3-D CT reconstructions provides the surgeon with the necessary information to develop an appropriate presurgical plan.

Surgical timing

Talar neck fractures often occur as a result of high energy mechanisms, resulting in open injuries in up to 20–38%,



Fig. 1 A comminuted Hawkins type III talar neck injury after a fall from two stories in a 18-year-old male with poorly controlled type I diabetes. Figure 1a–c: injury ankle radiographs. Figure 1d–f: postreduction radiographs showing tibiotalar and subtalar joints are now reduced.

Figure 1g–i: postreduction 3-D CT scan reconstructions. Note the significant medial and lateral talar neck comminution. Comminution is also seen within the medial aspect of the subtalar joint. The avulsion type fracture of the medial malleolus is better visualized

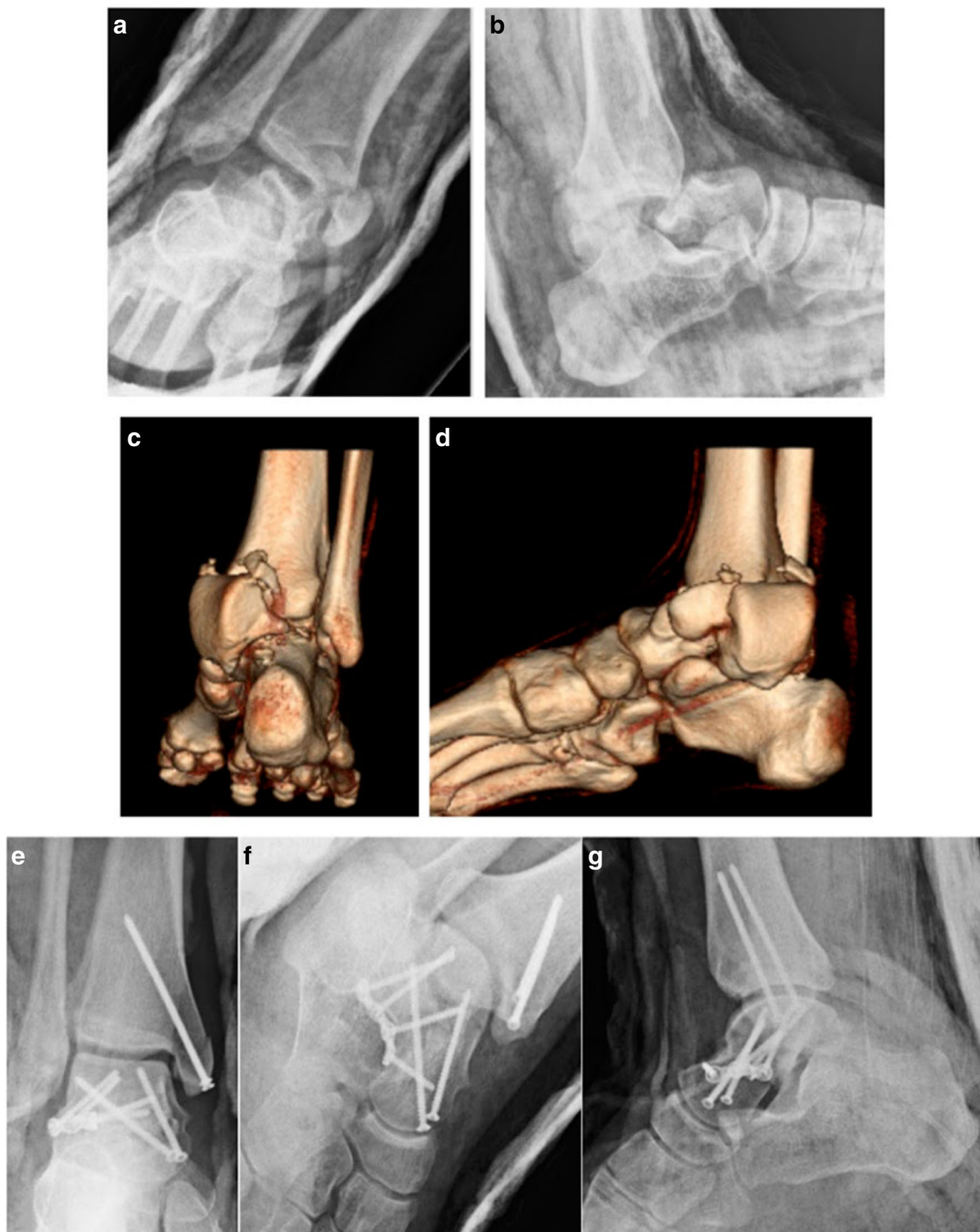


Fig. 2 Images of a 19-year-old female with a Hawkins III talar neck injury secondary to a motor vehicle collision. Figure 2a–b: initial radiographs displaying fracture at the talar neck-body junction with medial malleolus fracture. The tibiotalar and subtalar joints are dislocated and the talonavicular joint is reduced. The talar body is posteromedially dislocated but detail is obscured with the overlying splint material. Figure 2c–d: 3-D CT reconstructions demonstrating

complete posteromedial dislocation of the talar body. Figure 2e–g: this patient was taken urgently to the OR given the irreducible nature of the injury. Immediate postoperative radiographs after surgery. Dual incision approach was used with mini-fragment lateral plate fixation and medial screw fixation of the talar neck, and a 2.7-mm mini-fragment screw fixation of the medial malleolus fracture

and over 50% of patients have other fractures [2, 3, 5–7, 9, 26, 27, 32, 34, 35] (Fig. 3). Higher energy mechanisms can lead to disruption of the talar capsulo-ligamentous

structures with subluxation or complete dislocation of the talus, and even possibly talar extrusion [14•, 36] (Figs. 1 and 2).

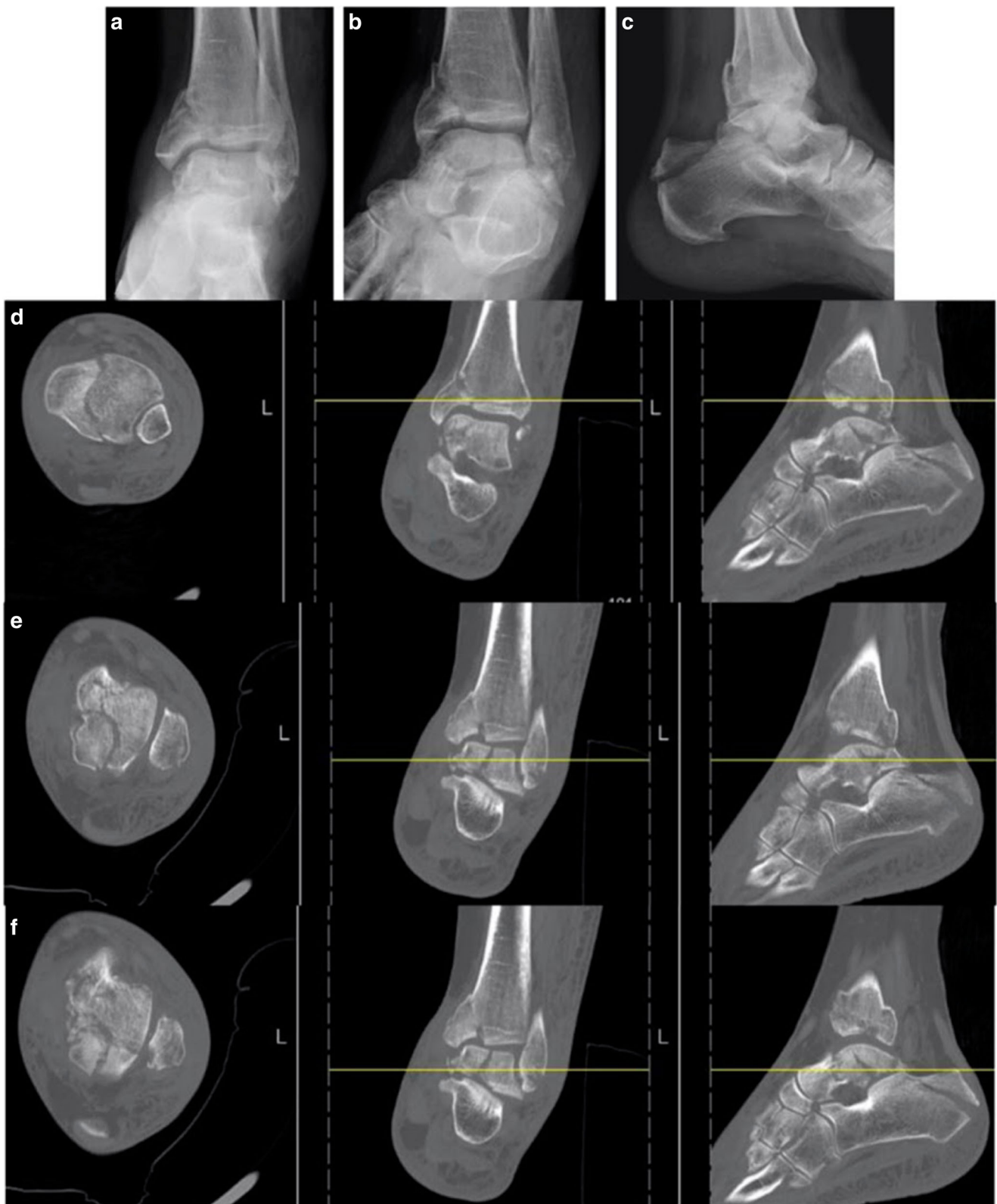


Fig. 3 Images of a 71-year-old female with rheumatoid arthritis who suffered injuries to the left tibial plafond, calcaneus, and talar neck and body after being struck by a motor vehicle. Figure 3a–c: initial radiographs displaying injuries. Figure 3d–f: representative 2-D CT

reconstruction images demonstrating full extent of all the injuries. Note the comminution of the medial talar neck and body. There is also medial plafond impaction

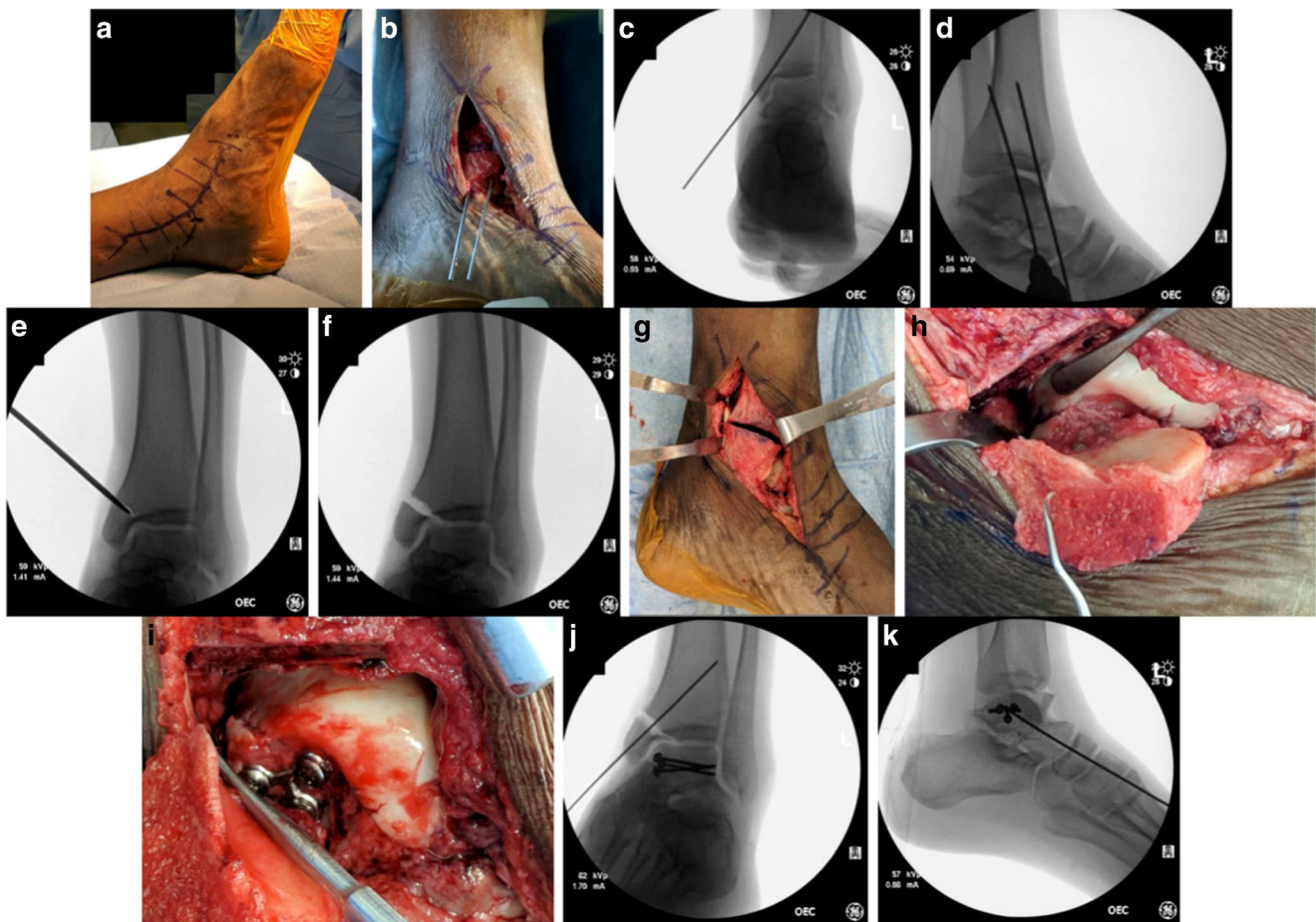


Fig. 4 Intraoperative images of surgical treatment of a talar neck and body fracture in 42-year-old male who fell from a ladder. Figure 4a: anteromedial incision. Figure 4b–g: medial malleolar osteotomy. Two 2.0-mm K-wires are placed perpendicular to the planned osteotomy. Figure 4h: medial malleolus displaced inferiorly with a dental pick to expose the medial talar body fracture and dome. Figure 4i: mini-fragment buttress plate fixation along the medial talar body. Figure 4j:

AP fluoroscopic ankle view of medial talar body buttress fixation. A K-wire is placed within the one of the predrilled holes of the medial malleolus osteotomy for temporary reduction to obtain appropriate fluoroscopic imaging. Figure 4k: lateral fluoroscopic view of medial talar body buttress fixation. A K-wire has been placed along the medial talar neck for initial talar neck preliminary fixation

Reduction of displaced talar neck fractures, subluxations, and dislocations should be done immediately upon patient presentation to protect the integrity of the soft tissue envelope and neurovascular status (Fig. 1). Open injuries, talus extrusions, and irreducible dislocations require emergent initial operative treatment (Fig. 2) [13•, 15•, 17]. Definitive fixation of talar neck fractures was historically treated with the same urgency [1, 2, 5, 26, 36–44]. It was theorized that fracture stability would preserve the tenuous blood supply after injury and thus reduce postoperative complications such as ON. However, recent literature supports that the time from injury to definitive fixation does not correlate with the risk of ON [6, 11•, 12•, 13•, 15•, 17, 27, 45–50]. Studies have shown that the development of ON is more related to factors associated with degree of initial injury, including initial displacement, comminution, and open fracture [6, 12•, 47]. The shift from urgent to delayed fixation has been reflected in clinical practice [51]. The important caveat to delayed definitive fixation,

however, is that the talar neck injury must be reduced. The current recommendation is to wait until the soft tissue envelope is amenable for definitive fixation as long as the injury is reduced [12•, 13•, 14•, 15•]. This can help minimize postoperative complications, such as wound dehiscence, skin necrosis, and infection, which despite this tempered approach, can reach up to 10% [6, 9, 27, 52].

Surgical approaches

Ultimately, the soft tissue envelope condition, the extent of the talar neck fracture, and associated other injuries (plafond, malleoli, foot) will dictate the surgical approach chosen. However, to optimize visualization of the entire talar neck, utilizing both the anteromedial (AM) and anterolateral (AL) approaches is currently advocated as the standard of care [6,

13•, 14•, 15•, 53, 54]. These two extensile approaches can also be combined with medial and/or lateral malleolar osteotomies for nearly complete visualization of talar neck and body injury to obtain anatomic reduction [6, 9, 13•, 14•, 15•, 17, 18, 55–58]. Only 15% of the posterolateral talar dome is inaccessible with combined medial and lateral malleolar osteotomies [59]. Distraction is also a valuable tool that can also be used for adequate visualization and reduction, and can be achieved through a variety of methods, such as shanz pins, external fixators, or specialized distractors [6, 56, 60–62]. The AM and AL approaches can also be easily incorporated for fixation of associated plafond injuries.

The senior author utilizes both AM and AL incisions to surgically address talar neck and body fractures similar to that described by Vallier et al. [6]. The patient is supine on the operating room table with a bump under the ipsilateral buttocks to rotate the extremity to a neutral position. The AM incision is centered over the medial malleolus, between the tibialis anterior and posterior tendons (Fig. 4a). Dissection is carried in full thickness fashion from the medial malleolus to the medial talonavicular joint, exposing the anteromedial talar body, medial talar neck, and head. If required, a medial malleolar osteotomy is performed for further exposure of the medial and posterior aspects of the talar body and dome [55]. The senior author prefers an oblique osteotomy exiting in the medial shoulder of the plafond. Prior to osteotomy, two 2.0-mm K-wires are placed perpendicular to the planned osteotomy (Fig. 4b–d). These serve as drill bits for two 2.7-mm fully threaded cortical screws, which are advanced in prior to osteotomy to “pretap” the trajectory of the final fixation. This enables easier fixation at the end of the case. After the screws are removed, the osteotomy is initiated with a microsagittal saw and completed with a thin osteotome to facilitate irregular fracture of the subchondral bone and cartilage, thereby helping with reduction during final fixation (Fig. 4e–g). After osteotomy, the medial malleolus is carefully retracted inferiorly on the preserved deltoid ligament, exposing the medial talar body and tibiotalar joint, allowing for appropriate fixation (Fig. 4h–k).

The AL incision is in line with the anterolateral border of the fibula proximally and the fourth ray distally (Fig. 5a). The proximal extent of the incision is usually to the level of the lateral malleolus. Proximal extension can be made if lateral malleolar osteotomy is needed. The literature is scarce with description of lateral malleolar osteotomy for talar neck fractures, and has been described more for addressing osteochondral talar dome lesions [58, 59, 63]. Distally, the incision is taken to the talonavicular joint. Full thickness flaps are again developed, taking care to identify any branches of the superficial peroneal nerve. Small branches that cross the incision that will hinder exposure are sacrificed. The fascia over the extensor digitorum longus and extensor brevis is incised, each muscle is carefully teased dorsally and plantarily respectively, and the sinus tarsi fat pad is excised,

for complete exposure. From proximal to distal, the lateral talar dome, body, lateral process of the talus, lateral talar neck, and lateral talonavicular joint are all visualized (Fig. 5b). The subtalar joint can also be visualized.

There are some instances where the medial malleolus or medial plafond is part of the injury (Figs. 2, 3, 6, and 8). In these cases, this medial fracture plane can be used similar to a medial malleolar osteotomy to address the talus injury. Care should be taken to ensure that the deltoid attachment to the medial malleolus is preserved. After reduction and fixation of the talus injury, reduction and fixation of the medial malleolus or plafond injury is undertaken. The senior author's preference of medial malleolus or plafond fixation is dictated by fracture pattern, mainly utilizing mini-fragment screws and/or plate methods (Figs. 2, 6, and 8). The senior author has found that mini-fragment screws (specifically 2.7-mm fully threaded cortical screws) allow for precise placement in the anterior and posterior colliculi of the medial malleolus in the vast majority of patients regardless of medial malleolus size and also provides adequate fixation. In the case of patients with larger anatomy, larger screws can be used. For medial malleolus osteotomy, it should be noted that bone loss from the thickness of the microsagittal saw will always be present, and therefore even though anatomic reduction of the joint surface will occur, there may be a gap seen at the osteotomy site on certain radiographic views (Fig. 5h).

There are multiple principles to follow during surgical approaches to prevent complications. It is important to avoid undermining and develop full thickness flaps and to ensure there is an adequate skin bridge between the AM and AL incisions [14•, 17, 18]. To minimize vascular insult to the talus, it is important to avoid dissection of the inferior talar neck and sinus tarsi, minimize stripping of the dorsal talar neck, and avoid injury to the deltoid ligament [13•, 14•, 17, 18]. Finally, careful inspection of the subtalar joint is important to remove any osteochondral fragments to ensure appropriate reduction. The senior author uses small straight and bent Hohmann retractors, freer elevators, and dental picks to help ensure meticulous surgical technique (Figs. 4g–i and 5b–d).

Limited AM and AL approaches have been described for the treatment of displaced talar neck fractures and when compared with standard AM and AL approaches, are reported to have similar outcomes [64]. However, despite concern over the amount of soft tissue stripping and potential ON that standard dual AM and AL approaches can cause, the literature has not demonstrated this to be true [6, 9, 15•, 52, 53, 65]. The common issues of medial talar neck comminution and/or impaction, malrotation, and neck shortening, can be avoided by combining the AM and AL approaches [13•, 14•, 17, 18, 42]. In the senior author's opinion and experience, standard dual AM and AL approaches allow for full visualization of the talar neck, providing the surgeon with the ability to

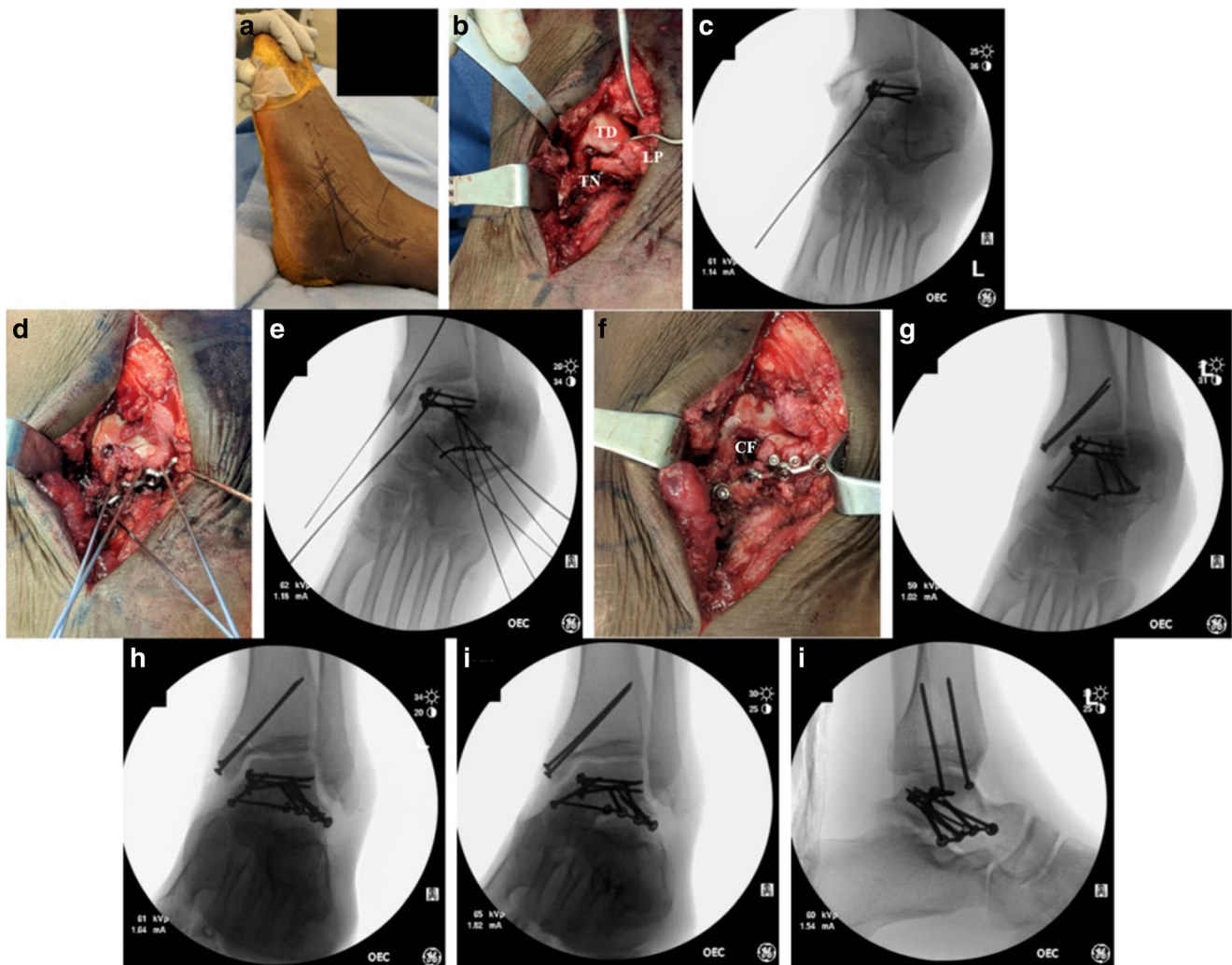


Fig. 5 Intraoperative images of the surgical treatment of a talar neck and body fracture in a 42-year-old male who fell from a ladder continued from Fig. 4. Figure 5a: anterolateral incision. Figure 5b: exposure of the lateral talar dome (TD), body, lateral process (LP), and lateral talar neck (TN). Note the comminution in the talar neck. Figure 5c: Canale fluoroscopic view of talar neck prior to lateral neck reduction and plate placement. Note the K-wire placement along the medial talar neck. Figure 5d–e: initial lateral neck reduction and K-wire placement with contoured mini-fragment plate extending from the lateral process of the talus to

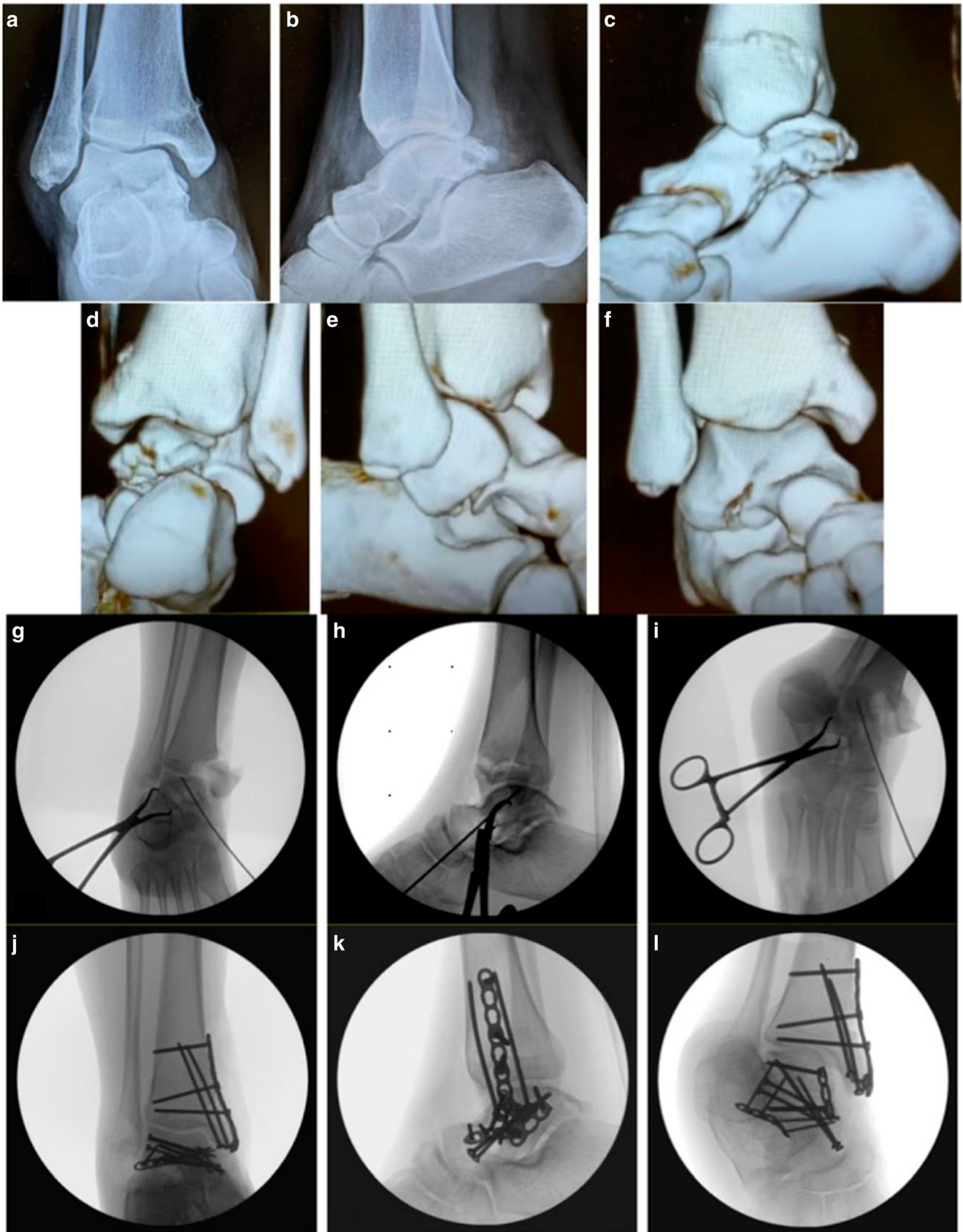
the distal extent of the talar neck. Figure 5f: view of lateral plate fixation with all K-wires removed. A comminuted fragment along the lateral neck which was used for initial reduction evaluation was removed (CF). Figure 5g–h: final fluoroscopic views after replacement of the medial K-wire with a mini-fragment screw for medial strut support of the neck and two 2.7-mm mini-fragment screws final fixation of the medial malleolus osteotomy. Note the gap seen in Fig. 5h (but not in 5i) at the medial malleolus osteotomy as a result of the thickness of the saw blade used to make the osteotomy

perform a more controlled dissection with less soft tissue stripping, accurately judge the reduction, and employ various fixation strategies.

Reduction is carried out using both incisions, ensuring appropriate length, alignment, and rotation of the talar neck. As the medial neck is often comminuted, reliance on lateral talar neck cortical reads is key to prevent varus malreduction. The senior author utilizes dental picks, small point-to-point reduction forceps, and K-wires, to obtain and maintain the reduction (Figs. 5b–e, 6g–i, 7a–d). Intraoperative fluoroscopy is vital to assess reduction of the talar neck and its articulations. It is imperative to obtain AP, LAT, and oblique, fluoroscopic imaging of the tibiotalar and subtalar joints in addition to the

Canale tangential radiographic view described for talar neck alignment [5, 28] (Figs. 5, 6, and 7).

Although the posterolateral approach to the ankle has also been described for the fixation of talar neck fractures, this approach is limited to simple fracture pattern types that are amenable to screw fixation as it does not adequately visualize the talar neck, and is fraught with complications (penetration of the subtalar joint and/or sinus tarsi; injury to the flexor hallucis longus tendon, peroneal artery, or saphenous nerve; possible restriction of plantar flexion of the ankle from screw head impingement on the plafond) [14, 17, 18]. The posteromedial approach to the ankle has been described to address talar body fractures to avoid the need for medial



◀ **Fig. 6** Images of a 22-year-old female with a Hawkins IIa talar neck fracture with medial talar body extension, and associated medial plafond injury after a severe twisting injury to her ankle. Figure 6a–b: Initial injury AP and LAT ankle radiographs. Figure 6c–f: 3-D CT reconstructions demonstrating posteromedial talar body comminution, subluxation of the subtalar joint, and lateral talar neck fracture. Figure 6g–l: intraoperative fluoroscopy showing open reduction internal fixation through dual incision approach. Medial plafond injury was carefully displaced along its fracture plane to access the medial talar body and dome. Anatomic reduction was obtained of the lateral neck with point to point reduction forceps based on cortical reads. Final fixation of the talar neck was completed with lateral mini-fragment locking plate fixation and supplemental retrograde mini-fragment screws as a medial strut. The medial talar body was addressed with a buttress mini-fragment locking plate. Fixation of the plafond injury was done with a combination of 2.7-mm screws and a mini-fragment locking plate

malleolar osteotomy, but again, this approach does not provide adequate visualization of talar neck [66]. With the increased use of arthroscopy in foot and ankle trauma, there has been some literature describing arthroscopic assisted reduction and fixation of talar neck fractures, but these techniques are again limited to simple fracture patterns [67–69].

Fixation strategies

There has been a move towards more stable fixation for talar neck fractures as implant technology has evolved. Prior to 1980, most talar neck fractures were reduced by closed or open means and then casted, with open reduction and screw fixation becoming more popular in the 1990s [12••]. The trend towards stable fixation has continued since the year 2000, with 96% of talar neck fractures reported in the literature treated with screw and/or plate methods [12••]. The senior author utilizes combined plate and screw fixation constructs based on fracture pattern and the soft tissue envelope. AO principles of anatomic reduction and stable, rigid fixation to maintain the reduction until union and to facilitate early range of motion, provides the foundation for the fixation strategy chosen.

Screw fixation alone is reserved for simple fracture patterns, where anatomic reduction can be obtained and no comminution is present, which could lead to collapse of the fracture and malalignment [14•, 17, 70]. The surgical approach undertaken and fracture pattern should dictate the direction of screw placement, as there is literature to support antegrade, retrograde, or combined constructs [71–74]. Screw size is dependent on fracture fragment size, and it is important either countersink screw heads or use headless screws to prevent impingement as biomechanical studies have shown no difference in strength [6, 13•, 14•, 17, 74, 75].

Lateral and/or medial plating has become a popular and more effective means of talar neck fixation. Plates can be augmented with independent screw fixation as needed. Although some biomechanical studies have demonstrated no

difference between screw only fixation and screw-plate constructs, plate fixation provides more precise reduction [72, 76]. The location of talar neck fracture comminution dictates plate position. Plates act as a bridging strut along the column they are placed on, creating a length stable construct, thereby resisting collapse and shortening. Several authors have also advocated primary bone grafting of areas of talar neck bone loss resulting from comminution to enhance stability of fixation constructs [6, 13•, 14•, 17•, 70, 74, 77]. However, other authors state that bone grafting should be reserved for non-unions or salvage procedures, especially with the use of plate fixation during primary surgical fixation [15•, 53, 54].

The senior author employs a combination of lateral and/or medial mini-fragment locking plate fixation augmented with mini-fragment screw fixation, based on the injury pattern (Figs. 2, 4, 5, 6, 7, and 8). The senior author prefers to use mini-fragment locking sets, which have 2.0-, 2.4-, and 2.7-mm screw and plate options, which are now readily available through several companies. In the author's experience, these sets provide the flexibility to select fixation options to address virtually all talus injuries and associated foot and/or plafond injuries.

Mini-fragment locking plate technology gives the flexibility of choosing nonlocking or locking screws to rigidly hold reductions of both the medial and lateral columns. The area of the lateral talar neck from the lateral process to the edge of the talar neck-head junction provides an excellent surface for plate application, as it does not articulate with surrounding osteology. Strategically sized K-wires are chosen to initially hold the fracture reduced, and are positioned either independently and/or through mini-fragment plates, such that they can be replaced with appropriately sized mini-fragment screws without having to re-drill (Figs. 4 and 5). Medial plate application has to be carefully planned to ensure no impingement within the medial tibiotalar joint gutter (Figs. 6 and 7). However, with varying thickness of mini-fragment locking plate options available, this issue can be easily avoided. Mini-fragment locking plates also provide multiple points of fixation and the buttress effect of the screws engaging into the plate is also advantageous, especially for areas of comminution.

As the senior author employs dual AM and AL approaches for the fixation of virtually all displaced talar neck fractures, most independent fully threaded cortical screws are placed as position screws in a retrograde (anterior to posterior) fashion, from the talar head articular surface along medial column (Figs. 2, 4, 5, 6, 7, and 8). Screws are either independent or augment the strut function of a medial plate. To facilitate appropriate K-wire and screw trajectory, the talonavicular joint is abducted, and sometimes the need to rongeur off the medial aspect of the navicular is needed. This avoids the need for a separate posterolateral incision and change in extremity position for appropriate fluoroscopy that has been described for posterior to anterior screw placement combined with AM and AL approaches [74].

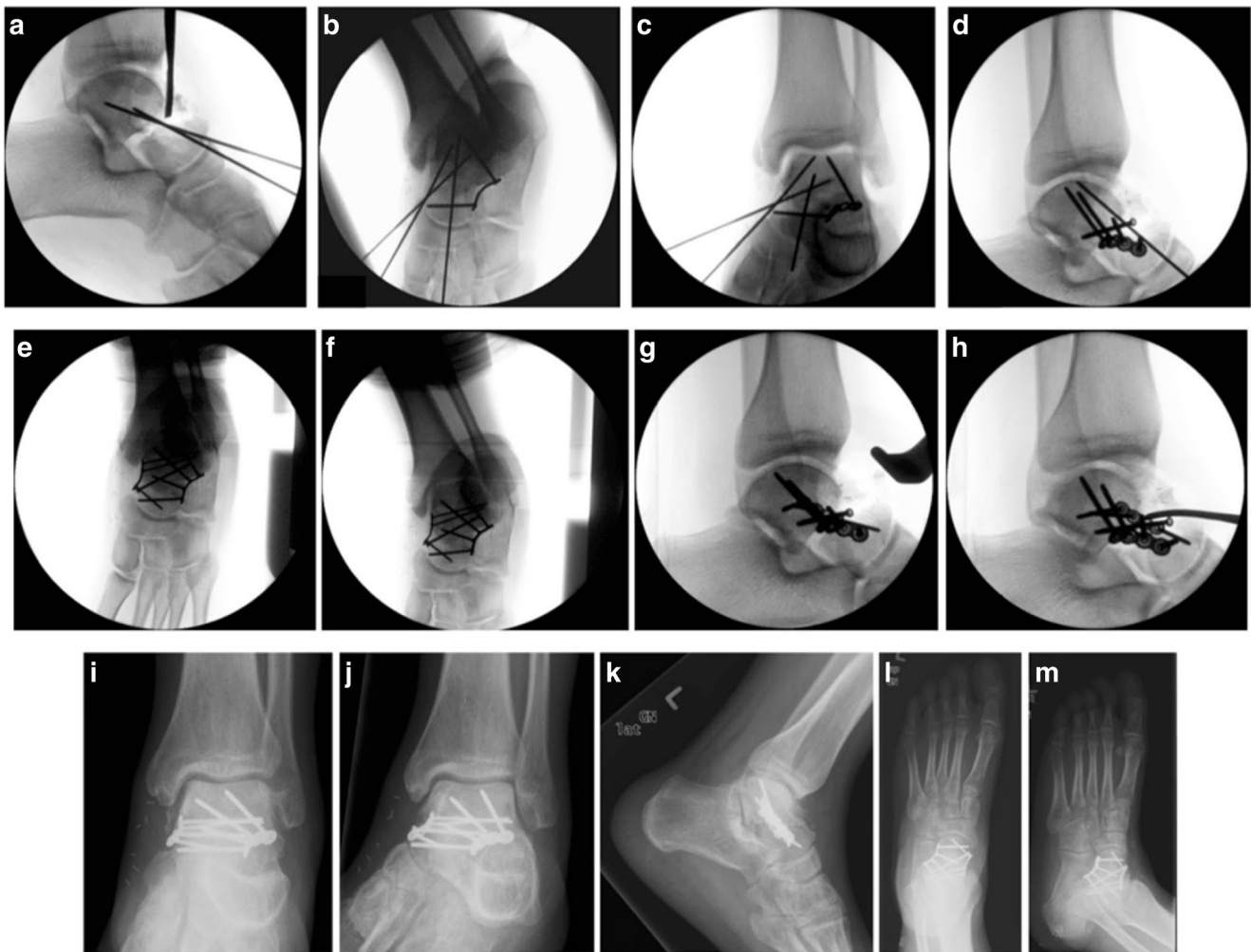


Fig. 7 Images of the Hawkins III talar neck fracture in the 18-year-old male shown in Fig. 1. Figure 7a: patient had delayed definitive fixation 10 days after the injury and reduction once his soft tissue envelope was amenable for fixation. Lateral ankle fluoroscopic view of initial reduction of talar neck fracture with K-wires through dual incisions. Note significant dorsal comminution and resultant bone loss as indicated by periosteal elevator. Figure 7b–d: Canale, ankle mortise, and lateral ankle fluoroscopic views of a subsequent lateral talar neck 2.7-mm mini-fragment locking plate application and placement of K-wires along medial talar neck. Figure 7e–f: due to the significant medial and lateral comminution and to maintain appropriate alignment, a 2.4-mm mini-fragment locking plate was placed strategically on the inferior medial

talar neck. Note the thickness of the medial plate in relation to the lateral plate to prevent possible impingement in the medial tibiotalar joint gutter. One of the medial K-wires was replaced with a 2.7-mm mini-fragment screw as supplemental strut fixation. Also note the differences in imaging with different angles of ankle eversion with Canale views obtained in Fig. 7e, f. Figure 7g–h: LAT and oblique LAT ankle fluoroscopic views demonstrating the significant dorsal comminution. This defect was filled with a viable cellular bone matrix. Figure 7i–m: ankle and foot radiographs 5-month postsurgery demonstrating excellent maintained reduction, healing of the talar neck fracture, and filling in of the dorsal bony defect

The senior author selectively uses primary bone graft on a case by case basis, depending on the fracture characteristics (comminution, bone loss, bone quality) and patient factors (age, comorbidities).

Complications and outcomes

Infection and soft tissue complications

A number of factors predispose the talar neck fractures to infection, including high energy mechanisms of injury,

high incidence of open injury, tenuous soft tissue envelope, and predominantly cancellous bone structure [2, 3, 5–7, 9, 15, 26, 27, 32, 35, 78]. In their systematic review of 21 studies by Halvorson et al., the overall deep infection rate for talar neck fractures was found to be 21%. However, the literature is somewhat heterogeneous, as only 16/21 studies with a total of 76 fractures, reported deep infection. Furthermore, only 14/21 reported their experience with open fractures, and only 6/14 of these studies reported their deep infection rate. As a result, a deep infection after open fracture has been reported as high as 38% [34].



Fig. 8 Images of left tibial plafond, calcaneus, and talar neck and body injuries of the 71-year-old female shown in Fig. 3. Figure 8a–d: patient had initial percutaneous fixation of the tongue type calcaneus fracture and placement of a spanning external fixator for her plafond and talar neck/body injuries as her soft tissue envelope was not amenable for definitive fixation. Figure 8e–h: patient was taken for definitive fixation 8 days later for when her soft tissue envelope improved. The medial plafond injury fracture plane was used to gain access to the medial talar body and dome. Initial medial to lateral screw fixation of the talar dome was performed. The talar neck was addressed with lateral mini-fragment locking plate

fixation and medial column medial column mini-fragment screw fixation. Figure 8i–l: after reducing the marginal impaction of the medial plafond injury, fixation was completed with mini-fragment locking plate and screw fixation. The fibular fracture was percutaneously fixed with retrograde IM screw fixation. Figure 8m–q: ankle and foot radiographs 5-month postsurgery demonstrating excellent maintained reduction, healing of the all fractures, and no signs of osteonecrosis. Calcium phosphate bone graft substitute was used to backfill the plafond impaction injury and is seen on the ankle radiographs

An expert opinion consensus exists regarding key principles to minimize soft complications and infections [11•, 12•, 13•, 14•, 15•, 16•, 17]. Significantly, displaced fractures and dislocations must be emergently reduced to protect the soft

tissue envelope and neurovascular status. Emergent operative management is reserved for those injuries that are irreducible and/or open. Open injuries also must receive appropriate antibiotics in a timely fashion and during surgery, all nonviable

tissue must be debrided using meticulous soft tissue technique. Following similar principles to other open lower extremity injuries, it is important to obtain timely soft tissue coverage for those wounds that are not able to be closed primarily closed, as this has been shown to decrease complication rates [79]. Negative pressure wound therapy can be used to bridge the time between initial debridement and time to definitive fixation and soft tissue coverage [80].

From the senior author's experience, treatment of infections should follow the same principles as treating other lower extremity infections. Acute infections require serial irrigation and debridement procedures with a combination of both local and long term intravenous (IV) antibiotics [15, 18, 81]. Chronic infections pose much more of a challenge. The senior author performs a staged treatment protocol with initial removal of all infected implants, debridement of all infected soft tissue and bone, the use of local and systemic antibiotics, and temporizing stabilization. If the infection clears based on clinical and laboratory examination, a second-stage reconstruction with a fusion procedure is performed (Figs. 9 and 10). Limb salvage route should be undertaken only after careful consideration of patient, fracture, and infection characteristics. Talar injuries complicated by infections result in poor functional outcomes and are at risk of amputation [11•, 15•, 34].

The current recommendation for definitive surgical fixation of reduced talar neck and associated foot and/or ankle injuries is to wait until the soft tissue envelope is amenable, which can take as long as 3 weeks [12•, 13•, 14•, 15•]. In the senior author's experience, strategic placement of a spanning external fixator is extremely helpful in temporarily stabilizing both the bony and soft tissue injury, and allows the soft tissue envelope to be carefully monitored (Fig. 9). Early dogma of immediate definitive surgery resulted in extremely high rates of skin necrosis, wound dehiscence, and infection, which have been reported as high as 77% [2, 3, 39, 82]. The utmost respect for the soft tissue envelope is key to avoiding these complications. Delayed definitive management has significantly decreased this incidence, but even with this precautionary approach, complications can still reach up to 10% [6, 9, 27, 52]. This further emphasizes the need for strict adherence to the principles outlined.

Osteonecrosis

There are three systematic reviews which provide the best current data for ON resulting from talar neck fractures [11•, 12•, 16•]. The overall incidence of ON varies in these studies from 26.47–33.3%. When stratified by Hawkins classification type, the overall ON rate is lower (23.6–26.47%). All three studies support the general trend of increasing ON rates with increasing severity of injury, as shown in Table 1. The significant variability in type IV fractures has been attributed to the rarity of these injuries.

It is important to note is that in studies performed from the year 2000 onwards, the overall ON rate dropped from 33.3 to 24.9%, and the most substantial changes were seen over time were with Hawkins type II and III fractures [12•]. This data reflects the paradigm shift in management of talar neck fractures described in this article, where recognition of the injury subtleties has substantially improved with the use of CT scan and the evolved standard of care is now dual incision approach and rigid fixation with modern techniques. Regardless of the actual incidence, multiple studies have demonstrated functional outcomes are significantly worse in patients who develop ON [3, 6, 15•, 47, 70]. As stated previously, there is no relationship between time to definitive fixation and ON, and factors related to the severity of the injury, such as comminution, open injuries, and subtalar dislocation increase the risk of ON [6, 12•, 13•, 14•, 15•, 47].

Despite the vast majority of studies using radiographs to make the diagnosis of ON, the actual radiographic definition in the literature is very poor [12•, 14•]. Increased radiodensity compared to adjacent osteology is the most common criteria used in the literature, and has been reported appearing anywhere from 4 weeks to 6 months after surgery [12•, 13•, 14•, 18]. Clearly, this is definition is extremely vague and subjective. Hawkins sign is a more useful prognostic radiographic finding for ON. It is defined as subchondral lucency appearing initially the medial talar dome on AP and mortise radiographs approximately 6–8 weeks after injury which progresses laterally and has been clearly demonstrated in the literature to be extremely sensitive but not specific [2, 5, 9, 12•, 14•, 15•, 18, 50, 62, 83, 84]. Therefore, although the presence of Hawkins sign indicates that talar vascularity is usually intact and progression to ON is rare, the absence of Hawkins sign does not equate to a diagnosis of ON. Studies have demonstrated that the talar body will revascularize without collapse in 37–44% of patients with radiographic findings of ON and that this can take up to 2 years after the injury [6, 13•, 15•, 17, 18, 27, 47, 50, 85]. MRI has been advocated to help clarify the diagnosis of ON, especially during the early postoperative period [12•, 14•, 17, 86]. However, MRI image quality will be affected by any retained implants, and therefore its usefulness will be limited unless implants are removed [87].

Observation and nonoperative treatment options, such as restricted weight bearing, an off loading orthotic brace (e.g., patellar tendon-bearing brace), and extracorporeal shock wave therapy, should be the first-line treatment for patients with symptomatic ON, as the risks of such treatments are low and there are no studies which show that functional outcome is compromised if surgery is required in the future [87]. However, nonoperative measures have not been shown to prevent talar dome collapse in the presence of ON. Talar dome collapse in the presence of ON has been shown to be

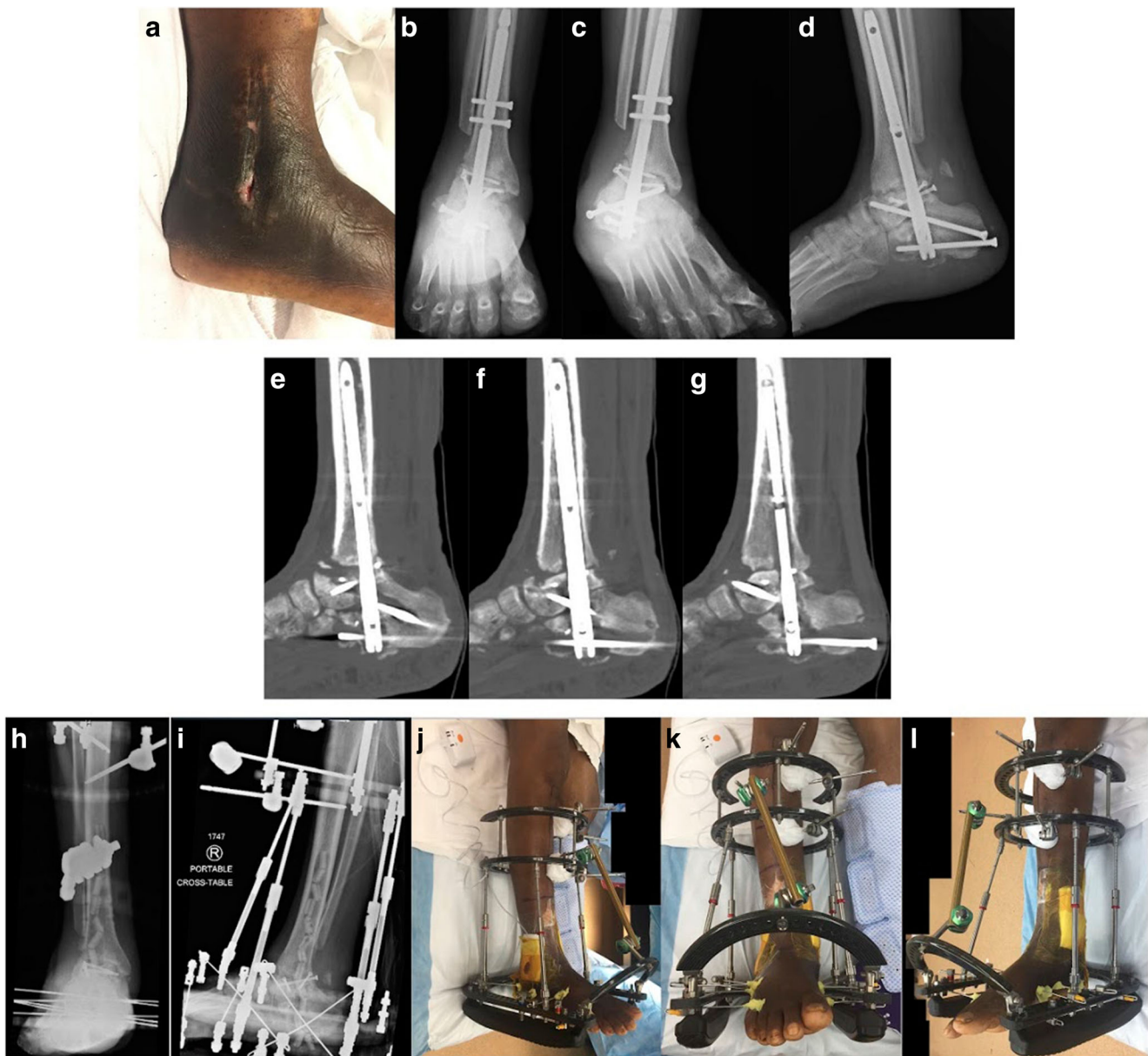


Fig. 9 Images of an infected nonunion in a 63-year-old male with poorly controlled type II diabetes and hepatitis C who suffered fractures of his right plafond, talar neck, and posteromedial talar body dislocation. Figure 9a: the patient presented with a chronic draining lateral wound 7 months after initial surgery where fibular excision, talus fixation, and primary tibiotalar and subtalar fusion with a TTC IM nail was performed. Figure 9b–d: presenting radiographs showing nonunion of the tibiotalar and subtalar joints with radiolucency around the TTC nail and screws. Figure 9e–g: representative sagittal CT reconstructions confirming nonunion of tibiotalar and subtalar joints with significant radiolucency around TTC IM nail screws. Patient had bone biopsy confirming pan

sensitive *Staph lugdunesis* infection. Figure 9h–i: patient wished to undergo limb salvage surgery. After 4 months of IV and oral antibiotics, the lateral draining wound healed. The patient was taken to the OR for first stage chronic infection treatment. The TTC IM nail was removed, irrigation and debridement of the nail tract with reamer-irrigator aspirator (RIA) system was performed, IM antibiotic impregnated calcium sulfate (CaSO₄) bullets were placed, and a circular frame fixator was used for stability. Figure 9j–l: clinical pictures of circular frame fixator with negative pressure wound therapy dressings over incisions that were used to remove TTC IM nails screws

unpredictable, occurring anywhere between 10 and 50% [6, 9, 15, 26, 39]. It is also important to keep in mind that more than half of patients with radiographic signs of ON are asymptomatic, and therefore initiation of treatment should be based on clinical symptoms, not radiographic findings [9, 14, 15, 17, 18, 87].

Operative treatment of talar ON should be considered when nonoperative measures fail and the patient becomes symptomatic. Operative treatment options are dependent on factors, such as the amount of bone affected by ON and the presence and degree of arthrosis. Ankle motion preserving procedures (custom talar prosthesis, total ankle arthroplasty) and arthrodesis

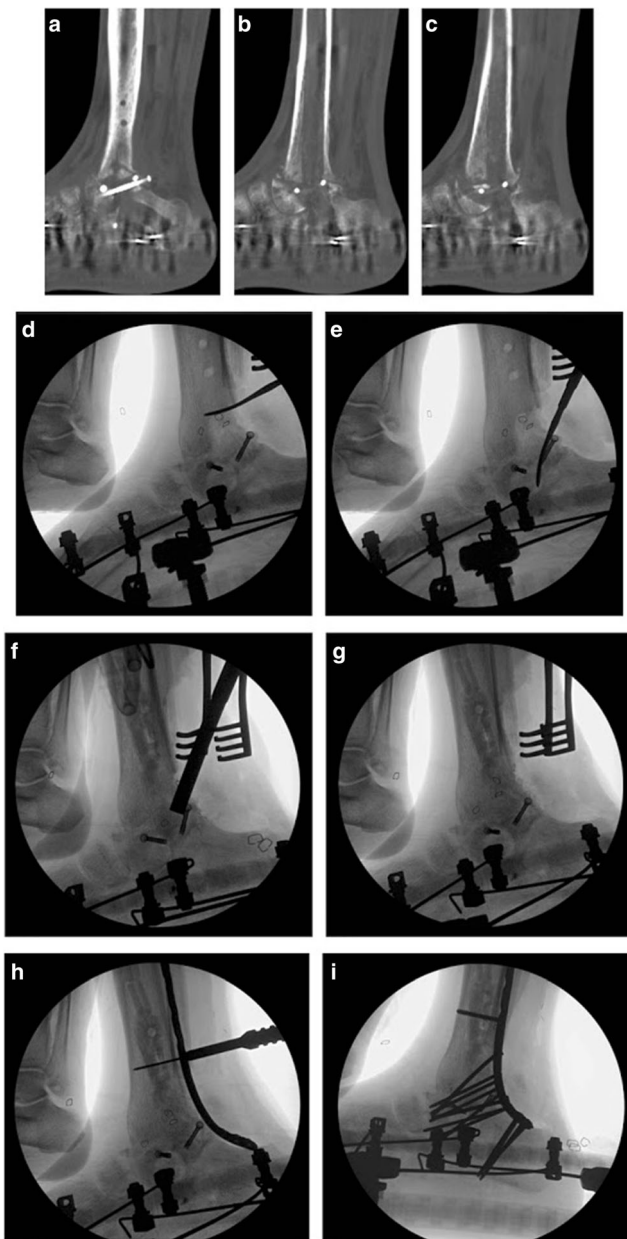


Fig. 10 Images of second stage tibiotalarcalcaneal fusion in the 63-year-old male from Fig. 9. Figure 10a–c: after 3 months of IV and oral antibiotics, the patient’s clinical exam and laboratory markers returned to normal. CT scan confirmed only partial bony bridging from distal tibia to calcaneus through what was left of the talus. Figure 10d–e: second stage chronic infection treatment. Intraoperative fluoroscopy showing bony defect after excision of all nonviable bone and tissue. Figure 10f–g: intraoperative fluoroscopy showing placement of antibiotic impregnated CaSO₄ bullets in the tibial canal and viable cellular bone matrix at the TTC nonunion site. Figure 10h–i: posterior plate TTC fusion using a medial distal tibia locking plate contoured to fit from the tibial shaft to the calcaneus. Circular frame fixator was left on postoperatively to protect the plate fixation

procedures (tibiotalarcalcaneal arthrodesis, modified Blair hindfoot fusion) have been described with variable results [14, 87]. Ultimately, the procedure chosen should be based on surgeon experience, patient factors, and the severity of ON.

Malunions and nonunions

The rate of talar neck nonunion is rare, quoted as less than 5% in review articles [11•, 13•, 14•]. In contrast, talar neck malunion has variable rates in the literature, with recent review papers reporting it as high as 20–37% [11•, 13•, 14•, 17]. Authors have suggested that this malunion rate may actually be underestimated given the difficulty of identifying and assessing malalignment on radiographs [11•, 13•, 14•]. These limitations have also contributed to the fact that no common radiographic definition or criteria has been established for malunion among studies. Furthermore, the changes over time that have been described in this article, such as CT imaging to recognize the extent of the injury, and surgical timing, approach, and fixation methods, all contribute to the variable malunion rates.

The key to avoiding malunion is careful preoperative planning to fix the fracture correctly at the time of initial definitive surgery. As stated previously, dorsomedial comminution is often present in talar neck fractures, and if not appropriately recognized and addressed at time of fixation, varus and extension malalignment will occur. Varus talar neck malunion is the most common deformity reported in the literature and will lead to altered subtalar and talonavicular joint biomechanics, thereby producing pain, poor function, and posttraumatic arthritis [4, 5, 13•, 14•, 18, 25, 33, 48, 88–90].

CT scan should be used to assess cases of suspected malunion. Treatment will again be dependent patient and osteologic factors, such as the severity of malunion, the presence and degree of arthrosis, and bone stock. Corrective osteotomies and bone grafting with plate and/or screw fixation constructs have been described in the literature [89–92]. Arthrodesis of the affected joints is the alternative treatment when an osteotomy is not a suitable option, but care has to be taken to ensure appropriate correction of the malunion deformity at the time of fusion.

Posttraumatic arthritis

Posttraumatic arthritis (PTA) is the most common complication after talar neck fracture, with recent systematic reviews citing an overall rate of 51.69–67.8% [11•, 16•]. The subtalar joint is most commonly involved, accounting for 38–49% in recent systematic reviews, but rises to 81% when only studies with a 2-year minimum follow-up are included [11•, 12•, 16•]. The tibiotalar and talonavicular joints are the next most commonly joints affected respectively, but a combination of all peritalar joints can be involved [11•, 15•, 17].

Once again, due to the heterogeneity of studies, breaking down the PTA data is difficult. Although most studies note PTA as a complication, it is often clumped into one general category without delineating the specific joint involved, and some studies do not even mention PTA. End-stage

radiographic findings of ON and malunion can also be similar to PTA. The criteria for PTA in studies are also inconsistent, using radiographic findings, clinical symptoms, or a combination of both. Although not every study examined PTA prevalence by fracture severity or classification, current literature supports the correlation between increasing PTA incidence with higher severity of injury [9, 15•, 16••, 17, 26, 36, 48].

Despite the high incidence of PTA reported, especially with longer follow-up, the rate of arthrodesis is surprisingly much lower, with the best evidence in the literature showing an overall fusion rate of 18.6% at a follow-up of 6 years [11••]. Therefore, despite the fact that PTA is the most common cause for secondary procedures, not all patients will be symptomatic and nonoperative management options should be considered first (oral analgesia, bracing, activity modification) [11••, 12••, 13•, 14•, 15•, 16••, 18, 27]. There is evidence that patients who do not require secondary procedure are more likely to return to their preinjury level of activity [48].

Operative management is again reserved for failure of nonoperative management and patient symptoms. However, due to the complexity and proximity of all the peritalar articulations, patient symptoms may be difficult to pinpoint. Diagnostic injections can be helpful to help guide treatment. Arthrodesis of the affected joint(s) is the current standard of care [12••, 13•, 14•, 15•, 16••, 17, 18]. Subtalar fusion (34.6%), tibiotalar fusion (20.3%), and triple fusion (16.5%) are the most common secondary procedures performed [11••]. Arthrodesis techniques will be dictated by the joints requiring fusion, with the goal to obtain a pain free, plantigrade foot. Open procedures with screw and/or plate fixation constructs, tibiototalocalcaneal (TTC) intramedullary (IM) nails, and arthroscopic assisted fusions, have all been described in the literature. Total ankle arthroplasty (TAA) can be considered as a joint motion preserving option if pathology is truly isolated to the tibiotalar joint and enough bone stock is available to support the talar component of the prosthesis. However, long-term data for this application of TAA is not available.

Functional outcomes

Similar to ON, there are three recent systematic reviews which best summarize the information on functional outcomes after talar neck fractures [11••, 12••, 16••]. No functional outcome measure was used in all studies. The most commonly reported was the Hawkins clinical evaluation tool followed by the American Orthopedic Foot and Ankle Society (AOFAS) ankle-hindfoot score [11••, 12••]. However, there have been no studies assessing the validity or reliability of either of these functional outcome measures for talar neck fractures, which makes it difficult to compare results between studies [12••, 93]. In the early 2000s, there was a shift from the Hawkins tool to the AOFAS ankle-hindfoot score in the literature [12••]. Irrespective of either functional outcome measure used,

studies consistently show that there is a correlation between poor functional outcome and increasing severity of injury [11••, 12••]. Although Jordan et al. showed that although there is a slight increase in AOFAS score between Hawkins type I and type II fractures, it then drops for type III and IV fractures. As expected, the development of ON and PTA also result in poor functional outcome scores [11••, 16••].

Conclusion

Despite the relative infrequency of talar neck fractures, there have been substantial efforts in recent years to better understand the nature and outcomes associated with this injury as well as best treatment options. The tenuous soft tissue envelope must be respected by focusing on urgent reduction of displaced fractures and dislocations. Ankle and foot radiographs and CT scans are used to identify the fracture pattern and associated injuries, and to be able to make an appropriate preoperative plan. Definite fixation should take place when the soft tissue envelope is amenable to minimize complications. Surgical focus should remain on anatomic reduction of the fracture and restoration of the peritalar joints through a dual incision approach and plate/screw fixation constructs to minimize the chance malunion. Although current data still report high rates of malunion, ON, and PTA, future research can be directed at determining whether modern treatment algorithms will decrease complication rates and improve patient outcome through validated means.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights and informed consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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