**Chapter**

# Calcaneus Fractures

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## Abstract

The calcaneus is the most frequently fractured tarsal bone, making up 60% of all adult tarsal fractures. While many calcaneus fractures can be managed nonoperatively, operative management of displaced, intra-articular fractures can prevent long-term deformity and may result in improved outcomes compared to nonoperative management. Three of the most common surgical treatment options are open reduction internal fixation, closed reduction with percutaneous pinning, and primary subtalar arthrodesis. This chapter reviews the epidemiology, relevant anatomy, biomechanics, clinical presentation, diagnosis, and management of calcaneus fractures.

**Keywords:** calcaneus, Sanders classification, sinus tarsi approach, external fixation, hindfoot fracture, heel fracture, extensile lateral approach

## 1. Introduction

Calcaneus fractures are the most common fracture of the tarsal bones, comprising 60% of all adult tarsal fractures [1]. The incidence of calcaneus fractures is 11.5 per 100,000 annually and occurs 2.4 times more in males than in females [2, 3]. The peak incidence for males occurs between 20 and 29 years, while for females, incidence peaks between 60 and 70 years of age [3, 4].

Calcaneus fractures are commonly present in younger populations due to a fall from a height [5, 6]. In osteoporotic individuals, the strong contraction of the gastrocsoleus complex through the Achilles tendon can cause calcaneal tuberosity fractures. Almost 77% of calcaneus fractures have associated injuries, highlighting the importance of a thorough evaluation for associated occult fractures in calcaneus fractures [7].

## 2. Anatomy

Understanding the anatomy and articulations of the calcaneus is crucial for diagnosing and treating calcaneus fractures (**Figure 1**) [8, 9]. The unique three-dimensional shape can make evaluation and conceptualization of surgical techniques difficult for the novice. The superior calcaneal surface contains three facets. The posterior, middle/sustentacular, and anterior facets articulate with the talus's anterior, middle, and posterior articular surfaces, forming the talocalcaneal (or subtalar) joint. The larger posterior facet of the calcaneus is convex, articulating with the talus above. The posterior facet is the major weight-bearing surface of the calcaneus. Due to the

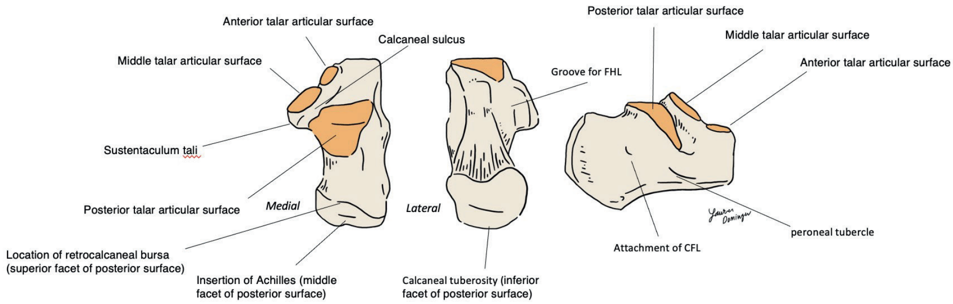


**Figure 1.**
*Anatomic landmarks of the calcaneus.*

high loads placed through the posterior facet, calcaneus fractures from axial loading often cause articular fragmentation. Anatomic reduction and fixation of the posterior facet are paramount to reducing the incidence of post-traumatic arthritis [10]. The calcaneus's smaller anterior and middle facets are concave in shape and separated from the posterior facet by the interosseous calcaneal ligament. However, a wide range of anatomical variations in the anterior and middle facets have been reported, ranging from a single ovoid-shaped facet to completely separated facets [11]. The middle facet lies on the superior surface of the sustentaculum tali. A posteromedial-directed groove called the calcaneal sulcus runs between the posterior and middle facets. A corresponding groove on the talus, called the sulcus tali, also runs between the posterior and middle facets of the talus. Together, these grooves make up the talo-calcaneal joint articulation and form the sinus tarsi (tarsal sinus/talocalcaneal sulcus) between the sulcus tali and calcaneal sulcus. Within the sinus tarsi lies an anastomosis between the peroneal and posterior tibial arteries and the cutaneous dorsolateral nerve of the superficial peroneal nerve [12]. Five ligaments are also contained in the sinus tarsi, the interosseous talocalcaneal ligament, the cervical ligament, and the medial, intermediate, and lateral root of the inferior extensor retinaculum. The primary function of these ligaments is to stabilize the talocalcaneal joint.

The medial surface of the calcaneus contains the sustentaculum tali (A.K.A. constant fragment). Superiorly, it sits against the middle talar articular facet. Inferiorly, this surface contains the groove for the flexor hallucis longus (FHL) tendon. The sustentaculum tali is bound to the talus by the interosseous talocalcaneal ligaments, spring ligament, and deltoid ligament. Fractures through the sustentaculum tali are rare and highly associated with intra-articular calcaneus fractures [13–15]. Due to the ligamentous connections on the sustentaculum tali, fractures are commonly nondisplaced [16], earning this portion of the calcaneus the term "constant fragment".

The lateral surface of the calcaneus has a bony prominence known as the peroneal tubercle. This structure lies in close relation to the tendons of the peroneus brevis and peroneus longus. The peroneus brevis passes anterior to the peroneal tubercle, and the peroneus longus travels inferior to it. The calcaneofibular ligament attaches proximally to the peroneal tubercle.

The posterior (nonarticular) surface of the calcaneus has three facets. The superior facet contains the retrocalcaneal bursa. The middle facet serves as the attachment for the Achilles tendon. The inferior facet forms the calcaneal tuberosity [17]. The anterior surface of the calcaneus contains the articular facet for the calcaneocuboid joint and the bifurcate ligament, which attaches the calcaneus to the cuboid and navicular.

## 3. Biomechanics

The calcaneus provides important static and dynamic functions of the foot and ankle. At rest, the static arch of the foot places 60% of weight-bearing stress on the plantar aponeurosis [18]. The plantar aponeurosis can absorb more stress as it becomes tauter, known as the windlass effect [19]. The windlass effect is essentially the tightening of the plantar fascia with dorsiflexion of the metatarsophalangeal joint, which elevates the medial longitudinal arch. The calcaneus's shape allows the plantar aponeurosis to change tension without collapsing the lateral or medial longitudinal arches [19]. The calcaneus dynamically supports movement and function with inversion and eversion through the subtalar joint, forming a rigid lever arm during toe-off and accommodating heel strike [20].

## 4. Classification

Some classification systems for calcaneus fractures have poor interobserver reliability, leading to difficulties in describing standardized treatment regimens [21]. Calcaneus fractures can be first classified based on whether they are extraarticular or intraarticular fractures, which account for approximately 25–40% and 60–75% of calcaneus fractures, respectively [22, 23]. Extraarticular calcaneus fractures are classified based on the location of the injury, including the anterior process, the sustentaculum tali, and the calcaneal tuberosity (which can be further classified with the Beavis classification).

The Beavis classification is based on the fracture morphology of the calcaneus tuberosity (**Figure 2**). A type 1 fracture or "Sleeve" fracture is an avulsion of the Achilles tendon with a small shell of cortical bone from the tuberosity. Type 2 or "Beak" fractures have oblique fracture lines that run posteriorly from the most superior portion of the posterior facet. Type 3 or "Infrabursal" fractures are avulsion fractures from the middle of the tuberosity.

Intra-articular calcaneus fractures can be classified with the Essex-Lopresti or the Sanders classification. The Essex-Lopresti classification is based on fracture lines using lateral radiograph images [24]. The primary fracture line runs through the posterior facet. The fracture is classified as tongue-type or depressed based on whether the secondary posteriorly exiting fracture line travels through or inferior to the calcaneal tubercle, respectively. However, the Essex-Lopresti classification has poor interobserver reliability [25].

The Sanders classification system uses coronal computed tomography (CT) scan images to determine the number of articular fragments at the widest point of the posterior facet at the level of the sustentaculum tali (**Figure 3**) [26, 27]. Sanders type I fractures are nondisplaced or have less than 2 mm of displacement, while type II fractures have one fracture line in the posterior facet with displacement. They are further separated into A, B, or C based on the primary fracture line location from lateral to medial. Type III fractures have two fracture lines in the posterior facet and are further separated into AB, AC, or BC based on the two fracture lines. Type IV fractures have three or more fracture lines.

The Crosby-Fitzgibbons system is another classification system based on CT imaging and was developed prior to the Sanders classification [10, 28]. The Crosby-Fitzgibbons classification system divides intra-articular facet fractures into three types. Nondisplaced or minimally displaced fractures are type I. More than 2 mm of

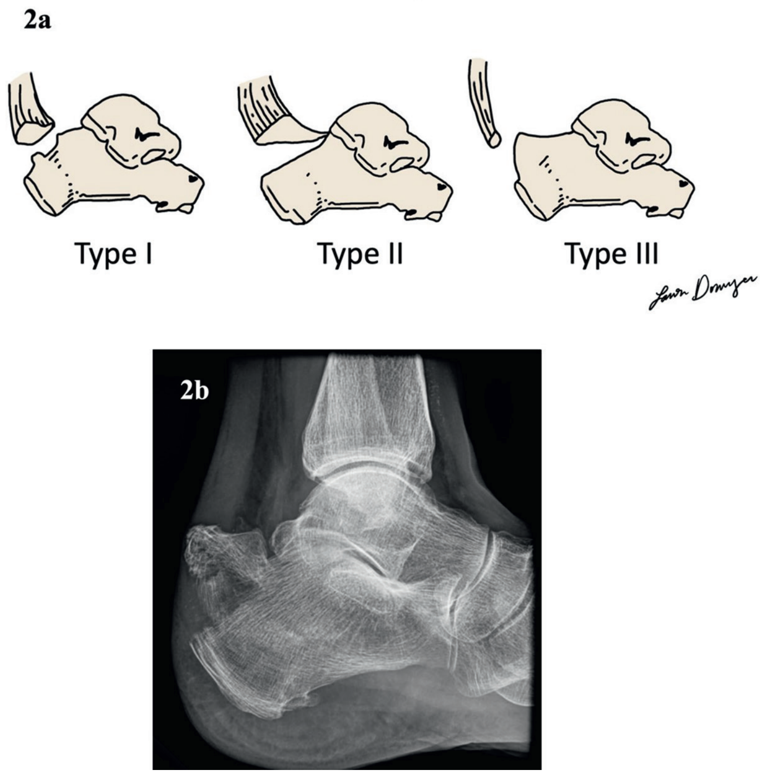


**Figure 2.**
*Beavis classification. (a) Illustration of Beavis classification of extra-articular calcaneus fractures. (b) Radiographic example of a type 2 "beak" fracture.*

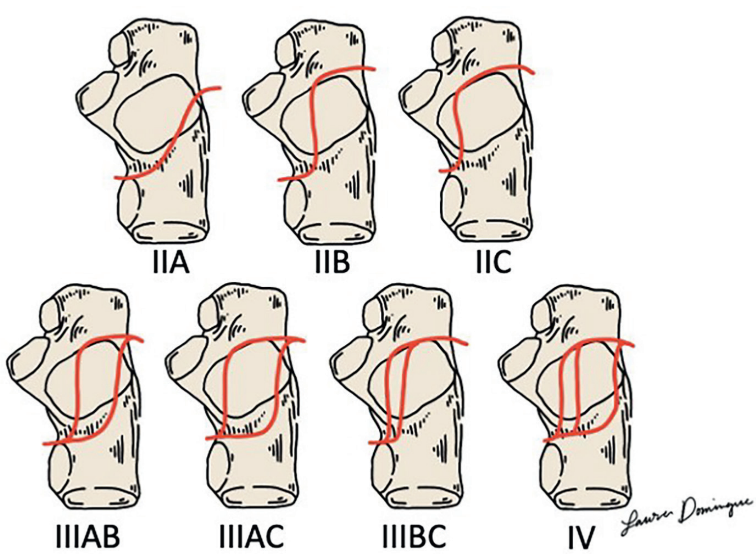


**Figure 3.**
*Sanders classification of intra-articular calcaneus fractures.*

*DOI: http://dx.doi.org/10.5772/intechopen.114132*

displacement or subtalar joint depression are classified as type II and comminuted fractures as type III. Lauder et al. [28] compared the Sanders classification to the Crosby-Fitzgibbons system and found that the Crosby-Fitzgibbons system had significantly greater interobserver reliability than the Sanders classification. Swords et al. [29]. compared the Crosby-Fitzgibbons to the Eastwood and Sanders classifications and found no significant difference in the ability to predict patient functional

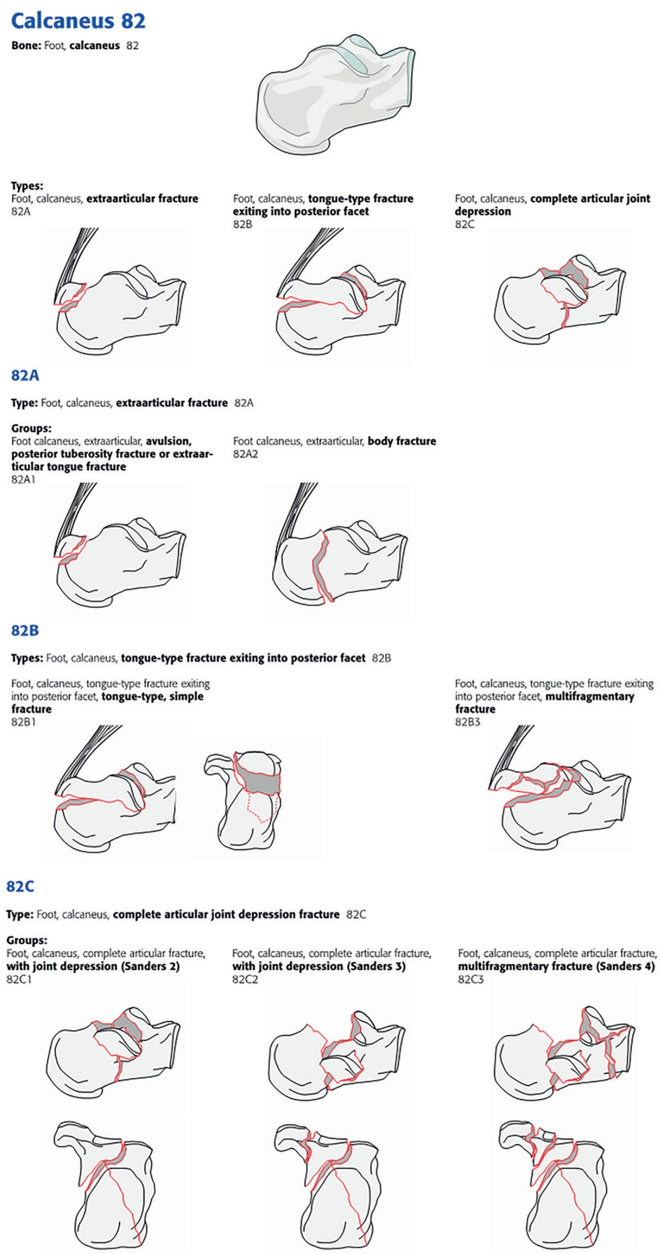


**Figure 4.**
*AO/OTA fracture classification of calcaneus fractures [30].*

outcomes using the Musculoskeletal Functional Assessment. However, the Sanders classification trended toward significance and had the highest predictive capability of functional outcomes.

The Müller/AO/OTA classification denotes the calcaneus as 82 and subdivides it into 82A, 82B, and 82C (**Figure 4**) [30]. Extraarticular fractures are classified as 82A, which is further divided into 82A1 for avulsion, posterior tuberosity, or extraarticular tongue-type fractures and 82A2 for extraarticular body fractures. Tongue-type fractures that exit into the posterior facet are classified as 82B1, 82B2 if there is associated joint depression, or 82B3 if highly comminuted. Complete articular fractures are classified as 82C. When there is joint depression with a single fracture line through the posterior facet, it is 82C1. If there is joint depression with two fracture lines (Sanders III equivalent), it is 82C2 and if highly comminuted (Sanders IV), 82C3.

The Regazzoni classification is a Swiss model for classifying calcaneal fractures [10, 31]. The Regazzoni classification system is based on coronal CT images. Type A fractures are peripheral fractures that are either extraarticular (A1), avulsion fractures of the sustentaculum (A2), or fractures of the anterior process (A3). Type B fractures are fractures involving the talocalcaneal joint. Type B fractures

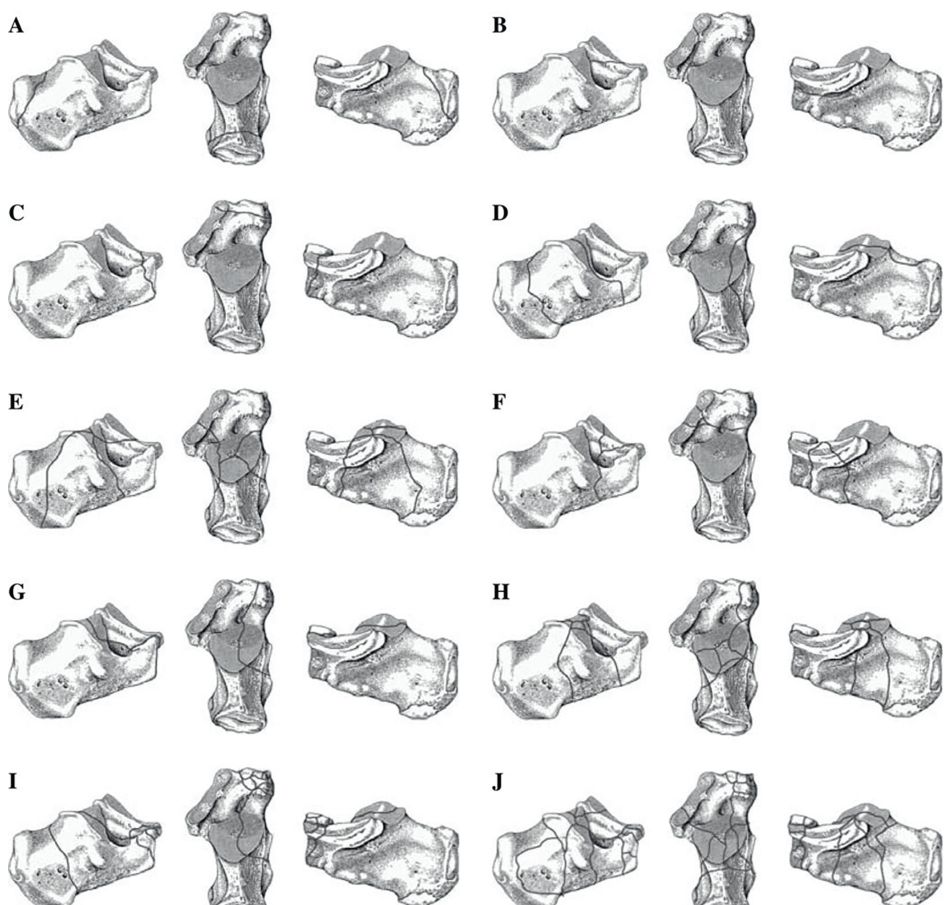


**Figure 5.**
*Regazzoni classification of intra-articular calcaneal fractures [32].*

can be those with single posterior facet fracture lines (B1), multiple posterior facet fractures (B2), and fractures involving the tarsal sinus (B3). Type C fractures are fractures of the talocalcaneal and calcaneocuboid joints. Single fracture lines in both joints constitute a C1 fracture. If one joint has multiple fracture lines or the tarsal sinus is involved, it is termed a C2 fracture. If multiple fracture lines involve both joints, it is a C3 fracture (**Figure 5**).

Rubino et al. [32]. compared the Essex-Lopresti, AO/OTA, Swiss Regazzoni, and Sanders classifications utilizing the American Orthopedic Foot and Ankle Society (AOFAS) hindfoot score, Creighton Nebraska Health Musculoskeletal Functional Assessment (MFA) Questionnaire, and other scores to determine the classification system with the best outcomes. Overall, the CT-based classifications had the highest prognostic values, particularly the Regazzoni and Sanders classifications.

## 5. Clinical evaluation/presentation

A thorough history and physical exam are essential for diagnosing calcaneus fractures. Important considerations of the patient's medical history, toxic habits, and daily activities (work status) are crucial as they affect outcomes. Pain and swelling are usually the first sign that a calcaneus fracture is present. Patients with these fractures may have other associated injuries that cause pain, which can lead to a delay in identifying calcaneus fractures. Although a rare occurrence in the authors' experiences, it has been reported that up to 10% of calcaneus fractures can lead to compartment syndrome [33]. Key components of the physical exam include visual inspection, neurovascular examination, and tendon function. Examination should include palpation and range of motion of the entire ipsilateral extremity and spine.

During visual inspection, ecchymosis and swelling of the heel, open skin lesions, or fracture blisters may be present. Tenting or ecchymosis may be visible in tuberosity fractures of the posterior calcaneus (**Figure 6**). Urgent surgical reduction is required if these findings are present to prevent posterior heel skin necrosis. Open skin lesions can present with calcaneus fractures (**Figure 7**). Urgent intravenous antibiotics, tetanus vaccination, and bedside irrigation are performed when open fracture is identified. After these urgent measures are taken, operative irrigation and debridement should be performed within 24 hours with concurrent temporary fixation with percutaneous pins, splinting, or definitive fixation with ORIF (described later in the chapter). Wound complications resulting from calcaneus fractures can be devastating and may require a free flap or amputation. Poor splinting techniques can contribute to posterior heel wounds. Therefore, to reduce the risk of splint/cast-related wounds, equinus can be allowed, and abundant heel padding is helpful.

Palpation typically elicits diffuse tenderness; in beak fractures, there will be a lack of posterior heel blanching. In avulsion fractures, there will be a heel cord continuity disruption. The neurovascular exam should include a comparison of the dorsalis pedis and posterior tibial pulses to the contralateral leg. Evidence of vascular insufficiency in the foot may require angiography or Doppler scanning. The primary targets when assessing tendon function should be the Achilles tendon and flexor hallucis longus (FHL). Decreased ankle plantarflexion strength occurs with avulsion of the posterior tuberosity, and weak flexion of the great toe points toward a displaced fracture entrapping the FHL.

Patients may also present with undiagnosed heel pain at times with negative radiographs. Concern for stress fractures should be present, especially in at-risk


**Figure 6.**
*Ecchymosis and fracture blisters due to tongue-type fracture. (a) Fracture blister and ecchymosis of the heel. (b) Ecchymosis of the heel due to a tongue-type fracture. (c) Radiograph of tongue-type fracture causing skin problems in (a).*


**Figure 7.**
*Open calcaneal fractures. (a)-(c)-open skin lesions due to calcaneal fractures.*

populations, including those with sudden increased physical activity, osteoporosis, or female athlete triad (menstrual dysfunction, low energy availability, and low bone mineral density).

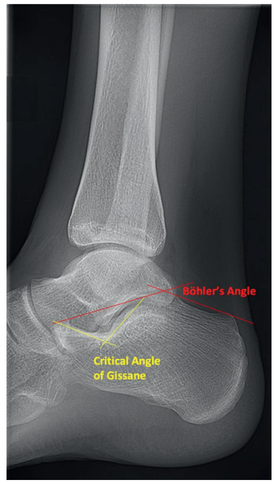


**Figure 8.**
*Radiograph showing Böhler's angle and the critical angle of Gissane.*

## 6. Radiographic evaluation

Standard ankle X-rays, including AP, lateral, and oblique views, can be supplemented with Harris and Broden views if there is a suspicion of a calcaneus fracture [34]. The Broden view visualizes the posterior calcaneus facet and subtalar joint, while the Harris view examines the tuberosity fragment, allowing for further characterization of the fracture. Radiographic measurements such as Böhler's angle and the Critical Angle of Gissane, normally between 20–40° and 120–145°, respectively, are important for identifying a collapse of the posterior facet (**Figure 8**). Still, normal measurements do not rule out a fracture.

CT scans are the gold standard for diagnosing calcaneus fractures and can guide surgical planning. CT scans are used to determine the Sanders classification as described above and provide additional detail regarding fragment size, displacement, and extent of intra-articular involvement beyond what is seen on plain radiographs. Magnetic resonance imaging (MRI) can be useful for calcaneus stress fractures. This should be considered when X-rays are normal, but there is high suspicion based on symptomatology, particularly in physically active patients [35, 36]. Furthermore, bone scintigraphy can be useful in individuals with metallic devices that would preclude MRI [37].

## 7. Treatment

Management of calcaneus fractures varies based on many factors. Nonoperative treatment is often recommended in extra-articular fractures with fragment size <1 cm in addition to less than 2 mm of displacement with an intact Achilles tendon. Nonoperative management is also indicated for Sanders Type I intra-articular fractures. Nonoperative management will typically consist of splinting and non-weight-bearing or toe-touch weight-bearing for 6–8 weeks with early range of motion of the ankle and hind foot to prevent stiffness [38, 39].

There is debate in the current literature on whether many calcaneus fractures are best managed with open reduction internal fixation (ORIF) or nonoperatively [10, 39–44]. ORIF has been shown to have greater rates of complications and repeat surgeries but with better outcomes regarding time to return to work and shoe fitting. ORIF was most beneficial in fracture patterns associated with fibular impingement, lateral comminution, and Böhler angles between 0° and 14° [40, 44]. Nonoperative management increases the risk of late subtalar fusion by 550–600% due to symptomatic subtalar arthritis [45, 46]. Additionally, without initial fixation and restoration of calcaneal height, the later subtalar fusion procedure increases in complexity due to the deformity created by the malunion of the calcaneus. The economic impact of treatment decisions must also be weighed. Concerning the impact on US healthcare payers, ORIF treatment costs almost $5000 less compared to nonoperative management over 5 years [47].

Operative management typically consists of ORIF, although external fixation for treatment of the calcaneus is well described (as discussed later in this chapter). ORIF can be performed through a traditional extensile lateral approach or minimally invasive approaches (**Figure 9**). Operative treatment aims to restore heel height and width, correct varus, and realign the subtalar joint. Operative indications include displaced tongue-type fractures with >1 cm of displacement; Sanders Type II, III, and IV fractures with articular displacement >1 mm; anterior process fracture with >25% involvement of calcaneocuboid joint; and displaced sustentaculum fractures [48].

Historically, ORIF has utilized the extensile lateral approach. This approach allows for excellent visualization of the subtalar joint by creating a full-thickness superior flap. It allows for the placement of a perimeter plate with fixation into the peripheral (more dense) bone of the entire calcaneus. The sural nerve and peroneal tendons are at risk during the approach and should be preserved. Meticulous and gentle soft-tissue handling should be observed (the so-called "no touch technique") [49].

Due to the risk of complications with ORIF, less invasive surgical techniques, such as percutaneous pinning, limited-incision sinus tarsi technique, and arthroscopic-assisted reduction and internal fixation, have been explored for fractures previously treated with the extensile lateral approach [50, 51]. While initially, the use of less invasive techniques had limited indications, these approaches have been shown to have equal clinical and radiographic outcomes to the extensile lateral approach with less wound-healing complications for all intra-articular calcaneal fractures [39, 51–53].

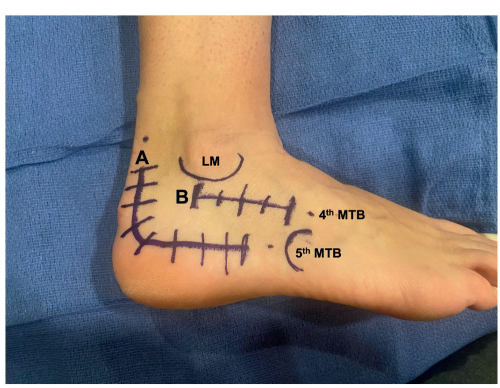


**Figure 9.**
*Extensile lateral approach (A) and sinus tarsi (B) approaches to the calcaneus. MTB = Metatarsal Base, LM = lateral malleolus.*

The sinus tarsi approach often utilizes a 2–4 cm incision over the sinus tarsi from 1 cm distal to the tip of the fibula toward the base of the fourth metatarsal. This approach provides direct visualization, reduction, and fixation of the posterior facet and calcaneocuboid joint while minimizing soft-tissue trauma [54]. This technique minimizes the risk of sural nerve injury and decreases surgical time and postoperative wound infections while enabling the surgeon visualization to restore the Böhler angle [51, 55–60]. The minimally invasive longitudinal approach (MILA) is an evolution of the sinus tarsi approach that takes the incision 1.5 cm distal to the lateral malleolus from the base of the fourth metatarsal to 1 cm anterior to the Achilles [54]. MILA has shown improved outcomes compared to the traditional sinus tarsi approach when using perimeter plates and compression screws [61], except in highly comminuted Sanders type IV fractures where the sinus tarsi approach was superior, most likely due to better visualization of the posterior facet [61].

Percutaneous fixation can be achieved with or without utilizing the limited sinus tarsi approach [53, 62, 63]. Percutaneous fixation can be performed using a variety of techniques to reduce fragments and maintain fixation with an external fixator or cannulated screws (**Figure 10**).

Arthroscopic-assisted reduction and internal fixation (ARIF) has shown excellent outcomes [64–66]. However, this technique may require increased setup, technical difficulty, and soft-tissue swelling, although disposable arthroscopy systems exist that may allow for similar visualization without the inconvenience of full arthroscopy setup [65]. When comparing less invasive techniques, there is no reported difference in radiographic restoration of Böhler's angle and clinical outcomes (AOFAS scores) [53].

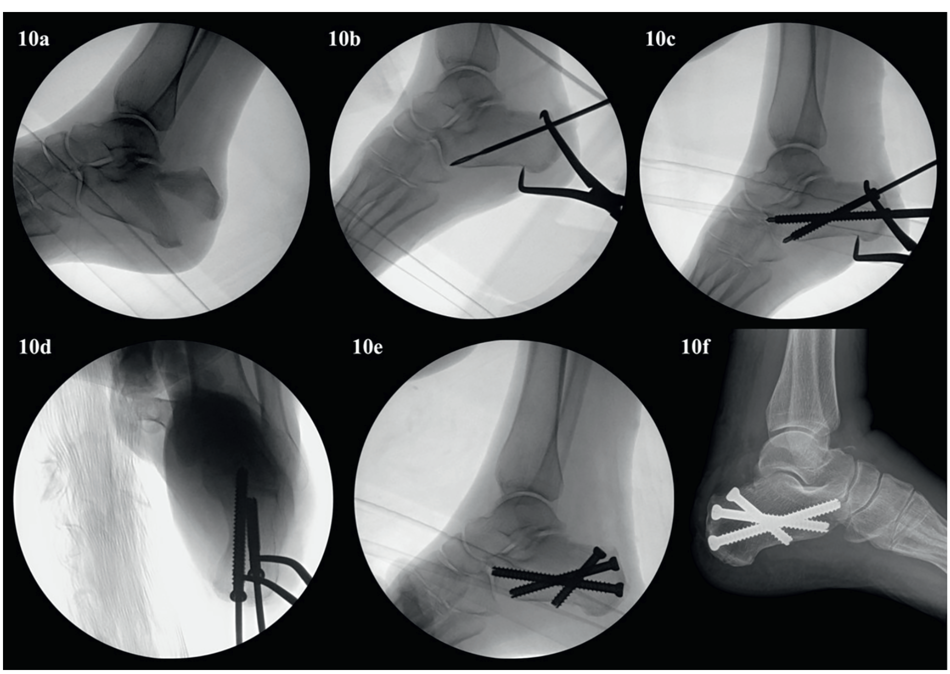


**Figure 10.**
*Utilization of percutaneous pinning for the fixation of a tongue-type calcaneal fracture. (a) Displaced tongue-type calcaneal fracture. (b) Reduction of displaced tongue-type fracture using a Kirschner wire. (c) Partially threaded and fully threaded cannulated lag screw placement for fixation. (d) Harris view of cannulated screw placement. (e) Final operative radiographs. (f) Postoperative radiographs.*

One study found an increased risk of secondary subtalar arthrodesis when performing percutaneous fixation due to subtalar osteoarthritis [67]. Percutaneous fixation is particularly indicated for patients with peripheral vascular disease or soft-tissue compromise in an attempt to avoid wound complications [52].

If these minimally invasive techniques are to be used, early treatment is indicated within 2 weeks due to early healing limiting fracture fragment mobility after this point [63]. Several studies have shown that minimally invasive approaches have decreased wound complications and secondary surgeries while having equivocal functional outcomes compared to ORIF [55, 57, 68].

In patients with severely comminuted Sanders type IV fractures, if ORIF alone is attempted, there is a high rate of clinically worse outcomes indicated by decreased AOFAS scores [69]. Sanders type IV fracture fixation can be done with ORIF alone, with some studies showing equal outcomes at 2-year follow-up when compared to ORIF with primary subtalar arthrodesis [69, 70]. However, beyond this time frame, there are decreased clinical outcomes utilizing the Short Form 36 version 2 (SF-36) scores requiring some patients with highly comminuted posterior facet calcaneus fractures treated with ORIF alone to undergo secondary subtalar arthrodesis [70]. Sanders et al. [43]. evaluated 10–20 year follow-up of ORIF treatment of Sanders type II and III fractures, showing a four times higher (18.6 vs. 47.4%) need for secondary subtalar fusion in type III fractures compared to that in type II fractures. Thus, some authors have suggested performing ORIF to restore height plus primary subtalar arthrodesis to avoid increased treatment costs and time off from work in fractures with higher degrees of comminution (**Figure 11**) [38]. However, it is difficult to predict which patients within this group of calcaneus fractures will develop chronic pain and eventually go on to arthrodesis, and this form of treatment can be a cause of its own downsides such as loss of motion and adjacent joint arthritis.

The importance of urgent reduction with percutaneous or open fixation of skin-threatening fractures cannot be overstated. Patients who sustain open fractures necessitating debridement and provisional stabilization and those with skin tenting, evolving wounds, or tongue-type/beak fractures should be initially splinted in

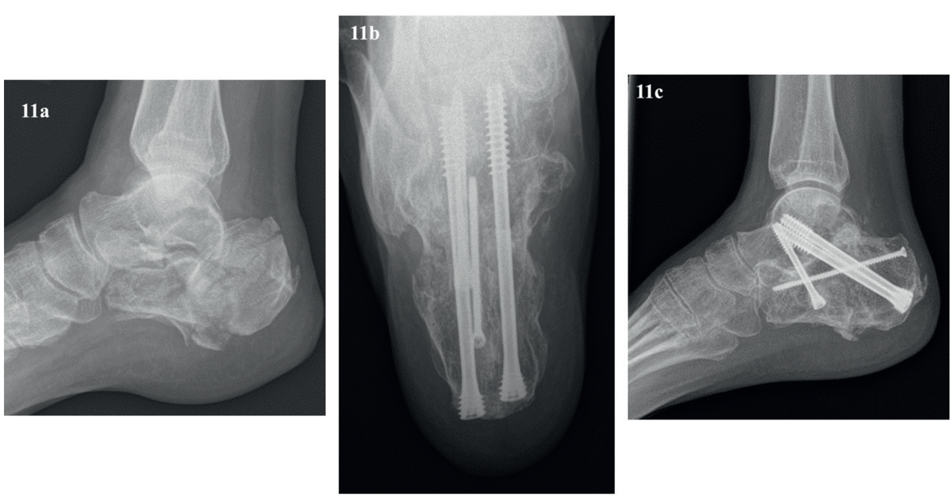


**Figure 11.**
*Primary subtalar fusion. (a) Highly comminuted intra-articular calcaneal fracture. (b) Harris view of the calcaneus after primary subtalar fusion. (c) Lateral view of the calcaneus after primary subtalar fusion.*

plantarflexion with abundant padding and then urgently addressed in the operating room in an attempt to prevent sequelae of skin necrosis and devastating wound complications.

External fixation is well described for calcaneus fractures in the literature as both a temporizing and definitive treatment option. With the high risk of soft-tissue complication with ORIF—even with minimally invasive approaches—external fixation has been further investigated as a treatment option. With the mechanism of action of calcaneus fractures primarily being due to high-energy trauma, the soft-tissue damage can be severe. Management often involves splinting the injury until the soft-tissue swelling has subsided. However, in more significantly displaced fractures, this delay in management can cause contraction of the soft tissues and preliminary callus formation [71–73]. These issues can combine to increase the overall difficulty of the surgical fixation for a calcaneus fracture [71–73]. As a result, there has been discussion in the literature of temporizing and definitive fixation of calcaneal fractures with external fixation.

Several external fixation methods have been proposed for calcaneal fractures, a testament to the lack of consensus and the overall difficulty of fracture management in these cases. Baumgaertel et al. described a minimally invasive external fixation approach of two-pin fixation, with one in each distal tibia and calcaneus to provide a distraction vector for the fracture, followed by lateral extensile ORIF [71]. The first pin is placed into the posterior calcaneus *via* a medial-to-lateral trajectory. The second pin is then placed either medial to lateral or anteriorly into the distal tibia. The pins are connected using an external fixator bar, and distraction force is applied. Overall alignment and reduction of the calcaneus is determined utilizing intraoperative X-ray and locked into position. The patients treated with external fixation followed by definitive fixation in their series had the external fixator in place for a median of 6.2 days [71]. The external fixator allowed for improved alignment and served as a reduction aid intraoperatively at the time of definitive fixation [71].

Githens et al. describe a medial-based fixator with pins in the proximal tibia, calcaneus, and midfoot to provide added construct stability while awaiting definitive fixation [73]. The first pin is placed across the midfoot medially, utilizing X-ray to ensure the tarsometatarsal joints are not violated with pin placement. The pin is placed across the medial, middle and into the body of the lateral cuneiform while under X-ray with a perfect AP view of the midfoot. The second pin is placed utilizing a medial to lateral trajectory into the distal tibia 1 cm above the incisura and parallel to the plafond. The third pin is placed into the calcaneus, typically the posterior tuberosity; however, the exact location of the pin can vary with fracture morphology. Importantly, the pin should be bicortical but not palpable on the lateral side. The first bar is placed between the tibia and the calcaneus, the second bar between the cuneiform and calcaneus, and the third between the tibia and cuneiforms (**Figure 12**) [73].

Ring frame external fixation combined with open operative approaches has been described in order to provide distraction, reduction of the articular surface, and internal fixation [74, 75]. Hou et al. describe the application of a ring frame external fixator utilizing 3, 2.5 mm Steinmann pins for fixation [75]. The first pin is placed transversely and perpendicular to the long axis of the tibia from lateral to medial at the junction of the middle and distal third of the tibia. The second pin is placed through the midfoot and the third through the posterior tuberosity of the calcaneus. The calcaneus and midfoot pins are each connected to separate half rings of the external fixator. The tibial pin is connected to a full ring of the external fixator. Connecting rods are placed between the tibial ring and the half rings of the midfoot and calcaneus. The midfoot

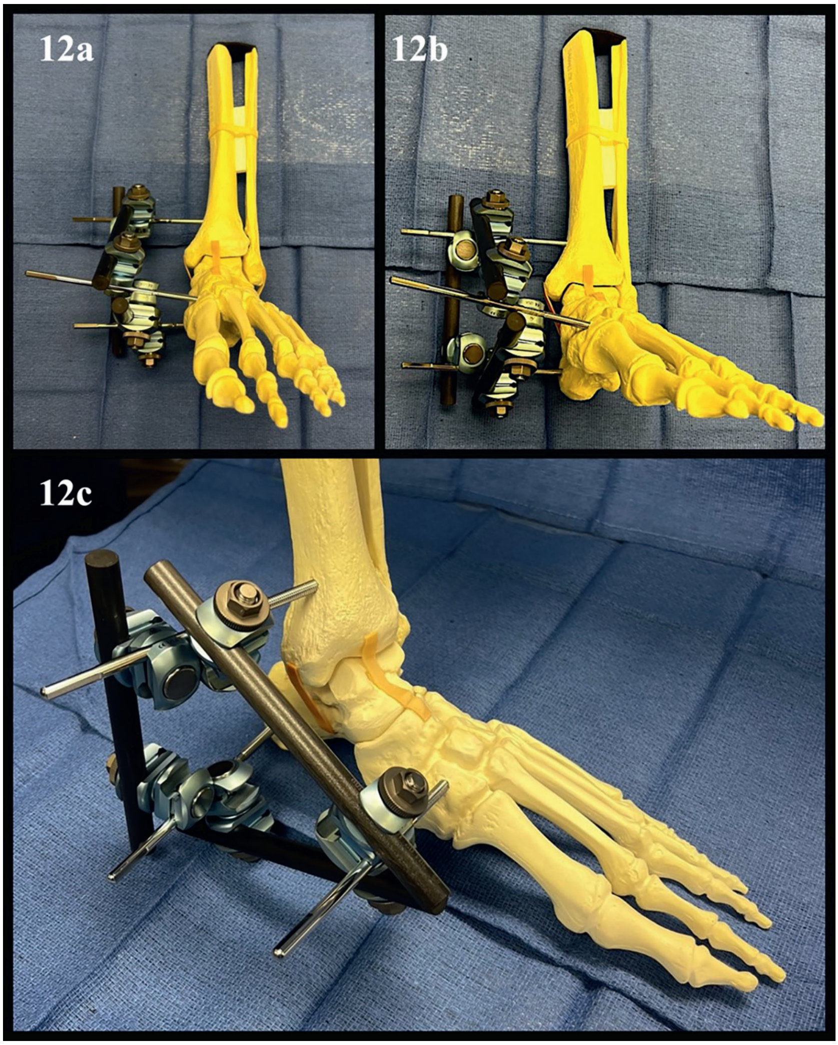


**Figure 12.**
*Calcaneus fracture external fixation technique as described by Githens et al. [73]. (a)-(c) sawbones demonstration of the medial-based calcaneal external fixator setup.*

and calcaneus half rings are joined *via* a single connecting rod directly inferior to the foot. Once the connecting rods are attached, they are left loose in order to perform the reduction. Utilizing intraoperative X-ray, the reduction is confirmed prior to locking the connecting rods. Once calcaneus length, height, Böhler's angle, and overall varus/valgus alignment are confirmed to be satisfactory, the limb is no longer manipulated and allowed to rest for 10 minutes. The goal of the 10-minute rest is to allow soft-tissue relaxation. After 10 minutes, an extensile lateral approach is utilized for fracture fixation. Once fixation is achieved, the external fixator is removed [75]. The senior author of the current chapter (JTR) has utilized a similar ring frame construct utilizing skinny wires, half pins, and external fixator struts in order to bring the calcaneus fracture out to length as temporary or definitive management (**Figure 13**).

Fu et al. described a series of patients treated with fixator-assisted reduction. Their patients were initially treated conservatively with rest, elevation, ice, and

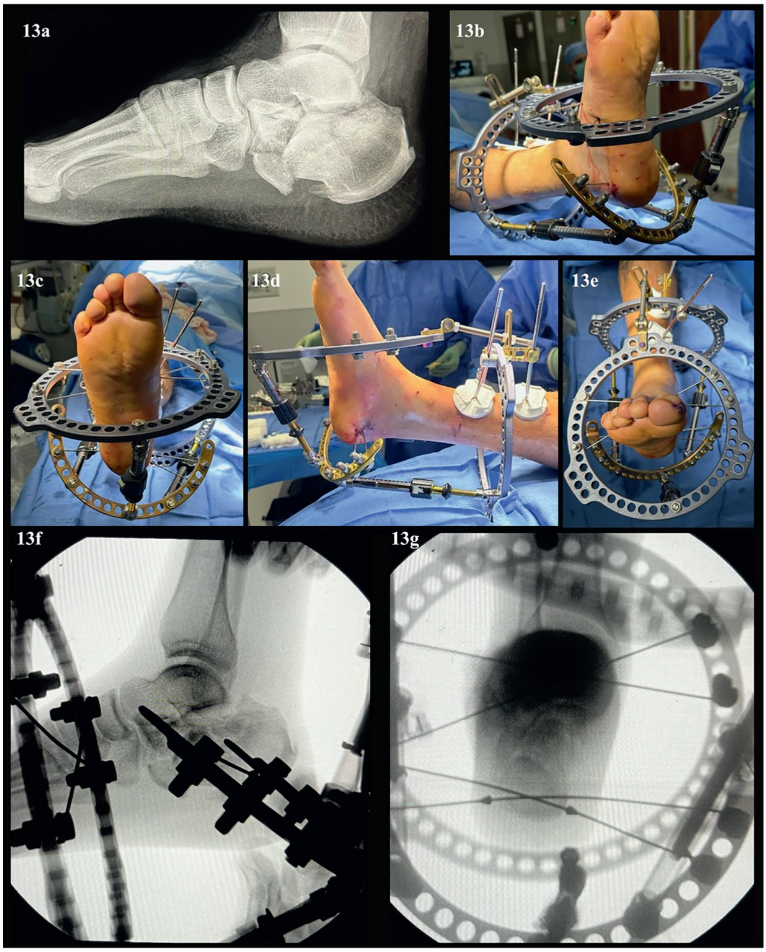


**Figure 13.**
*Calcaneus ring frame technique (JTR). (a) Preoperative X-rays. (b–d) Clinical pictures of ring frame, skinny wires/tibial half pins, and struts. Wires are utilized for fixation into the calcaneal tuberosity and into the midfoot, while half pins provide tibial fixation. After rings have been connected to wires/pins, the calcaneus can be manipulated (pulled out to length and out of varus) and struts locked. (f–g) Postoperative external fixation X-rays.*

compressive bandages with planned operative management to follow [74]. Splinting materials were not used, and ankle and foot motion was encouraged to reduce swelling. Once the swelling had subsided, operative treatment was performed. A lateral extensile approach was utilized, and an external fixator was applied to aid in reduction. With their technique, two transcalcaneal full pins are placed in the posterior calcaneus, with two half pins placed anterior-posterior into the distal tibia (**Figure 14**). Once adequate internal fixation is achieved, the external fixator is locked with the ankle in a neutral position. The external fixator remains in place for approximately 3 months postoperatively [74].

Studies have also discussed using external fixation as the definitive treatment of these fractures. Checa-Betagón et al. described a series of 38 patients where external fixation was utilized as the definitive treatment [76]. In their series, they utilize a lateral-based external fixator (OrthoFix™ Calcaneal Fixator) with six half pins (3 pin clusters) placed into the calcaneus (posterior tuberosity, subchondral bone of

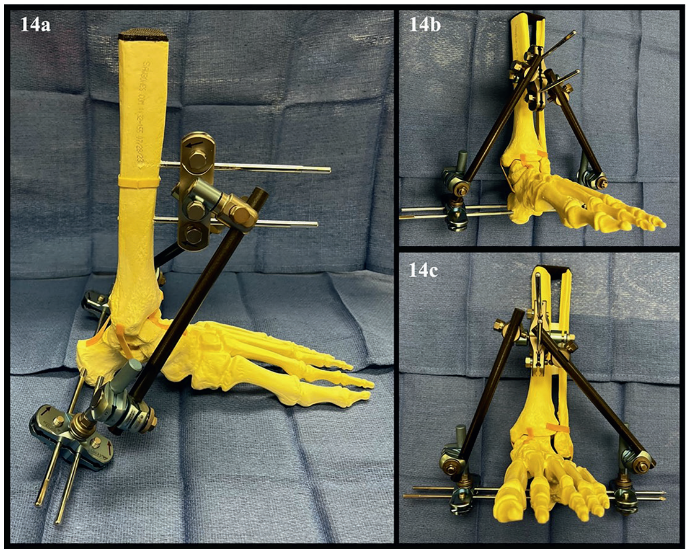


**Figure 14.**
*Calcaneus fracture external fixation technique as described by Fu et al. [74]. (a)–(c) sawbones demonstration of external fixator setup for use in fixator-assisted delayed ORIF.*

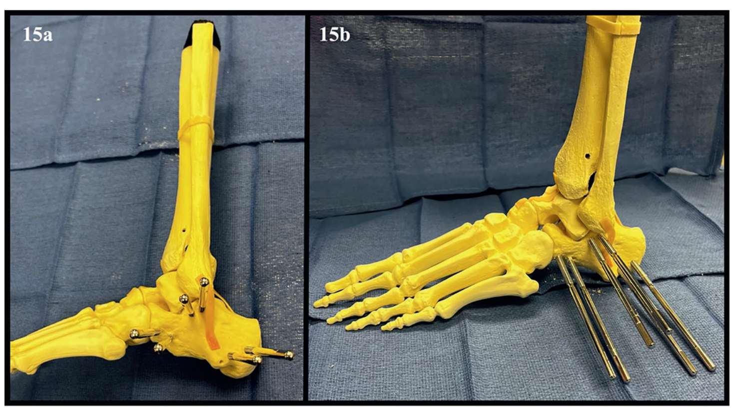


**Figure 15.**
*Calcaneus fracture external fixation technique as described by Checa-Betagón et al. [76]. (a) and (b) sawbones demonstration of the pin sites for lateral-based OrthoFix™ external fixator for use in definitive treatment.*

the posterior facet, or available subtalar surface) and the anterior tuberosity of the calcaneus or the cuboid (**Figure 15**). Pin clusters are placed in line with the X-ray beam when a perfect lateral view of each structure is seen individually. 69% of cases were reduced indirectly, while the remaining 31% required a minimal sinus tarsi approach or percutaneous k-wire joysticks to assist with reduction. They report results of external fixation to be similar to ORIF while reducing the risk of soft-tissue complication [76].

## 8. Treatment algorithm

The following treatment algorithm was created to aid in successfully managing calcaneus fractures (**Figure 16**).

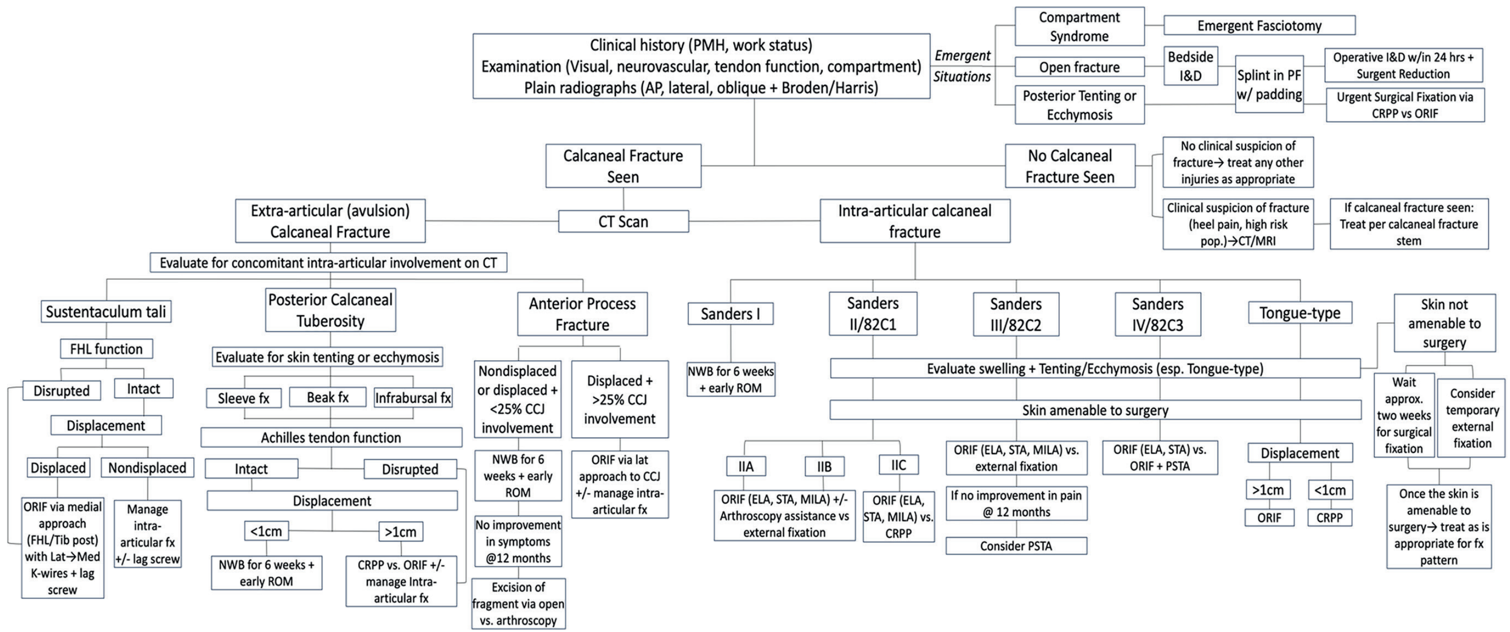


**Figure 16.**
*Treatment algorithm for calcaneus fractures. (PF = plantarflexion, ORIF = operative reduction and internal fixation, PSTA = primary subtalar arthrodesis, NWB = non-weight-bearing, ROM = range of motion, ELA = extensile lateral approach, STA = sinus tarsi approach, MILA = minimally invasive longitudinal approach, FHL = flexor hallucis longus, FWB = full weight-bearing, CRPP = closed reduction and percutaneous pinning, CCJ = calcaneocuboid joint, fx = fracture.*

## 9. Complications

Calcaneus fractures are prone to many complications based on the high-energy nature of these injuries and the calcaneus's thin, soft tissue envelope and anatomic relationship to many soft-tissue structures. Predominant complications consist of post-traumatic arthritis and wound-healing issues. Up to 37 and 20% of operations utilizing the extended L-shaped lateral incision have wound difficulties [50].

Long-term follow-up indicates that patients who undergo fixation of Sanders type III fractures are four times more likely to require subtalar arthrodesis compared to those with type II fractures [43]. This can be attributed to both the difficulty associated with treating these fractures and a testament to the overall high-energy mechanism responsible for most of these fractures. Inadequate articular reduction of the posterior facet can result in progressive loss of the joint [77]. Furthermore, subtalar arthritis can arise even with an anatomic articular reduction due to the chondrocyte damage sustained during the initial injury [77, 78]. Management of post-traumatic arthritis begins with conservative treatments similar to other joints. Over-the-counter anti-inflammatories, shoe-wear modification, bracing, activity modification, and other conservative modalities are first attempted. As conservative management fails, surgical options to be explored involve arthrodesis of the subtalar joint and other joints affected with post-traumatic arthritis.

Wound-healing problems represent one of the most common complications following surgical treatment of calcaneus fractures, with reports citing complication rates up to 25% [79–81]. The strongest risk factors for wound breakdown include diabetes, smoking, increasing Sanders type, and open fracture [79, 80]. Management of wound complications initially involves oral antibiotic therapy with local wound care for minor wounds. As the size of the wound increases beyond minor dehiscence, operative intervention is required, utilizing increasing levels of surgical debridement and soft-tissue reconstruction. Cavadas et al. propose an algorithm of soft-tissue management in calcaneal fractures utilizing a local subcutaneous transverse flap, a sural subcutaneous flap, and a distal vastus lateralis free flap, depending on the wound severity and patient factors [82]. The study defined minor wounds as <1.5 cm, moderate as 1.5–5 cm, and extensive as >5 cm. All wounds and fractures healed in the study [82]. Furthermore, Krishna et al. provide an algorithm for treating heel wounds utilizing wound location and weight-bearing status as a guide for soft-tissue reconstruction selection [83]. Local rotation and advancement flaps were very useful for small defects. Moderate anterior heel defects were treated with a medial plantar artery flap, and complete defects were treated with an extended reverse sural flap. The islanded reverse sural flap was utilized for posterior heel defects [83].

Additionally, neurologic injury is a common complication experienced in calcaneal fractures. When utilizing an extensile lateral approach, the most common injury involves the sural nerve, specifically the sensory cutaneous nerve [77, 84]. With a medial approach, the tibial nerve is at risk, with the calcaneal branch being most at risk [84, 85]. Management of this injury initially involves medications, including gabapentin, shoe inserts to accommodate the area of injury, and physical therapy [77, 84]. When there is failure of conservative management of the nerve injury, operative neurolysis and burying of the nerve into deeper tissue can be employed [77, 85, 86]. Regarding nonsurgical treatment of calcaneal fractures, posterior tibial nerve entrapment is the most common neurologic complication [77]. Treatment of this entrapment involves the treatment pathway of nerve compression with conservative management initiated first, followed by surgical decompression if necessary.

Malunion of calcaneal fractures is a well-documented complication. Consequences of malunion include but are not limited to: increased heel width, subfibular impingement, tibiotalar impingement, varus/valgus deformity at the hindfoot, peroneal tendon dysfunction, and subtalar arthrosis [77, 86, 87]. For isolated lateral impingement symptoms, lateral wall decompression can provide good results. However, more complex deformities require further operative planning and management [87].

Flexor hallucis longus pathology remains another complication worth noting. Damage to the FHL tendon can occur due to displaced fracture and misplaced screws into the sustentaculum tali during reconstruction. Misplaced screws can penetrate the opposite cortex inferior at the sustentaculum tali and directly impinge on the FHL tendon [88]. Treatment involves screw removal and replacement in this setting.

## 10. Conclusion

Calcaneus fractures are common lower extremity fractures requiring a comprehensive knowledge of anatomy, an attentive clinical and radiographic evaluation, and an understanding of surgical techniques for appropriate management. Initial evaluation of calcaneus fractures must consider the mechanism of injury and the potential for associated injuries. As operative indications and treatment for calcaneus fractures continue to evolve, there is a focus on minimizing, delaying, or preventing arthritis while minimizing wound complications. External fixation can restore length, rotation, and alignment while decreasing the risks associated with internal fixation of calcaneus fractures. Sinus tarsi approaches also show promise with decreased soft-tissue complications and similar patient-reported outcomes. Wound breakdown remains the most significant and potentially devastating complication of these fractures. After wound complications, neurologic injury and other soft-tissue injuries are common, while malunion and its sequela are well-documented bony complications.

## Acknowledgements

The authors would like to thank Lauren Domingue, for the drawings of the Anatomic Landmarks of the Calcaneus, Beavis fracture classification, and Sanders fracture classification. The authors would like to thank Mark Hetzer and Isabelle Annaheim from Synthes GmbH, Oberdorf, Switzerland, for the drawings of the Regazzoni [31] fracture classification. The authors would also like to thank Synthes for providing the external fixator equipment and sawbones used in demonstrations.

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