EMJ Online First, published on March 3, 2016 as 10.1136/emermed-2016-205706

Osseous injuries of the foot: an imaging review. Part 3: the hindfoot

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Received 12 January 2016
Accepted 14 January 2016

Linked

▶ http://dx.doi.org/10.1136/emermed-2015-204807
▶ http://dx.doi.org/10.1136/emermed-2016-205704

To cite: Kiener AJ, Hanna TN, Shuaib W, *et al*. *Emerg Med J* Published Online First: [*please include* Day Month Year] doi:10.1136/emermed-2016-205706

ABSTRACT

Injuries to the foot are a common cause for presentation to the emergency department, and imaging is often used to aid in the diagnosis. The foot can be divided into three distinct anatomic regions: the forefoot, midfoot and hindfoot. Our manuscripts comprise a three-part imaging review in which we address the use of radiography as well as advanced imaging modalities. We provide pearls to radiographic interpretation and discuss prognostic implications and classification systems. Part 1 addresses forefoot injuries, part 2 reviews midfoot injuries and part 3 covers the hindfoot.

INTRODUCTION

This three-part series reviews the radiological diagnostic approach to fractures and injuries of the foot. This article is the third instalment and will centre on the osseous injuries to the adult hindfoot. The hindfoot is composed of the talus and calcaneus, which bear significant physiological stress during walking and running. Understanding the functional action of the hindfoot allows the clinician to conceptualise both the cause of certain injuries and the result of traumatic deformities. Apart from intrinsic weight bearing needed to support the force of ambulation, the main functional concern of the hindfoot is subtalar mobility.[1] Because the point of contact of the heel is lateral to the centre of the ankle joint, subtalar eversion is initiated at the onset of standing. This subtalar valgus stress results in internal rotation of the talus, rotating the medial aspect of the foot into solid contact with the ground.[1] This action reverses during terminal gait as the forefoot contacts the ground. To optimise evaluation of the hindfoot, dedicated three-view foot radiographs should be augmented by dedicated three-view ankle radiographs; this is particularly important in evaluating the talus, as well as the distal tibia and fibula, which may be associated with hindfoot fractures.

ISOLATED HINDFOOT INJURIES

Calcaneus

The calcaneus is the largest tarsal bone and articulates with the talus to form the two subtalar (talocalcaneal) joints along the anterior, middle and posterior facets of the superior calcaneal surface and with the cuboid anteriorly, forming the calcaneocuboid joint.[2]

Calcaneal fractures

Calcaneal fractures are the most common tarsal fracture, accounting for up to 60% of all tarsal fractures.[3] The mechanism of calcaneal injury is usually a fall, where an axial load forces the calcaneus to divide (figure 1). This results in a sustentacular fragment and a tuberosity fragment as the dominant portions of the divided calcaneus.[3] The sustentacular fragment remains stable in location due to the strong attachments of the deltoid ligaments. The tuberosity fragment, however, moves lateral with axial loading because it lacks stabilising ligamentous attachments.[4] A thalamic fragment, made up of a depression of the calcaneal posterior facet, may also be present in case of a sustained compressive axial force.[3]

Calcaneal fractures can be classified into extra-articular and intra-articular fractures. Extra-articular fractures are caused by low-energy trauma, inversion and tendon avulsions. The extra-articular fracture of the anterior process of the calcaneus is an increasingly recognised injury, with rates cited anywhere from 3% to 23% of all calcaneal fractures.[5] These injuries are often mistaken for ankle sprains, and thus the exact incidence is unknown. The proposed mechanism of injury is inversion on a plantar flexed foot.[6] This fracture has a higher incidence in females, possibly due to dressing in high heels.[6] Careful clinical examination of a patient with this injury will show maximum tenderness 1 cm inferior and 2 cm anterior to the anterior talofibular ligament.[5] In this clinical setting, close inspection of the anterior process of the calcaneus on lateral ankle or lateral foot radiographs is warranted (figure 2). Continued clinical concern in the setting of negative radiographs in the acute setting warrants CT.

Intra-articular fractures are more commonly a result of high-energy trauma (such as jumping from a height or a motor vehicle collision) and are described in several classification systems. The Sanders Classification is commonly used (although its reproducibility has been questioned[7]). Sanders uses roman numerals to denote the severity and letters to denote fracture location (table 1). The higher the number, the more severe the fracture. For type III fractures, two letters are used to denote the location of the two primary fracture lines. For example, a Sanders type IIIBC fracture would be an intra-articular calcaneal fracture with two primary fracture lines located in the central and medial aspects of the bone.

In the emergency department (ED), intra-articular fractures are most often diagnosed initially by foot or ankle radiographs using standard anteroposterior, oblique and lateral radiographic views. In most cases, the lateral view will show depression of the posterior facet and a decrease in Bohler's angle (an imaginary line drawn from the

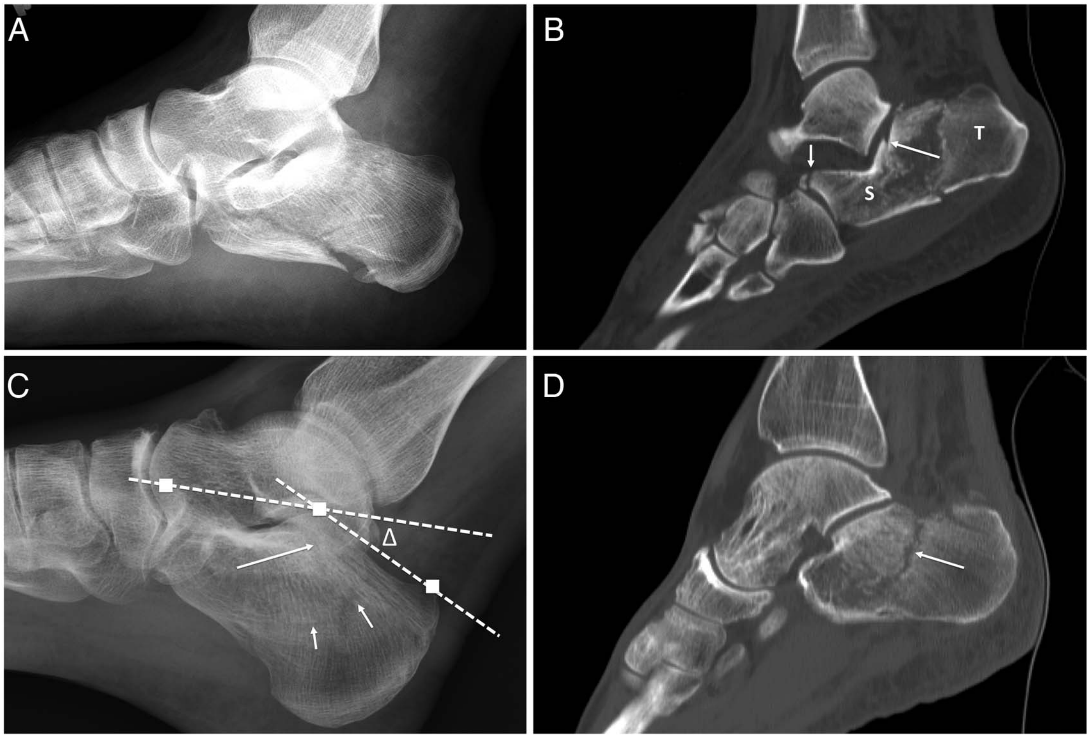

Figure 1 Calcaneal fractures. (A) A 42-year-old man with an acute intra-articular calcaneal fracture on lateral radiograph and (B) sagittal CT. Fracture extends into the posterior calcaneal facet (long arrow). An associated fracture of the anterior calcaneal process is noted (short arrow). T indicates the tuberosity fragment while S indicates the sustentacular fragment. (C) A 56-year-old woman with a much more subtle acute intra-articular calcaneal fracture. Lateral radiograph shows subtle trabecular disruption with linear lucency (short arrows), compatible with acute fracture. Fracture was suspected to extend into the posterior facet (long arrow). Boehler's angle is the theoretical angle created by lines connecting the highest points of the anterior and posterior calcaneus on the lateral view (these points are shown as white squares); it is the angle created by the dashed lines (Δ) and is normally between 20° and 40°, as in this case. It may be, but is not always, decreased in calcaneal fractures. (D) Sagittal CT confirms calcaneal fracture (arrow). Fracture extended into the posterior facet, and nearly to the calcaneocuboid joint (not shown).

most superior part of the posterior facet to the most superior part of the anterior facet, normally 20–40°).[2 3] In osteopenic or osteoporotic individuals with non-displaced fractures, close evaluation of the calcaneal trabeculae for discontinuity may be the only evidence of fracture on plain radiographs. The anteroposterior (AP) view allows localisation of the distal portion of the primary fracture line. Lateral, modified Broden and Harris–Beath radiograph views of the calcaneus can provide further evaluation in the setting of negative initial foot radiographs with continued clinical suspicion. CT is also indicated in intra-articular fractures as it provides a clearer view of the fracture to assist surgical procedures.[3] Whether this CT is performed in the ED or at follow-up orthopaedic evaluation will depend on local practices.

Talus

The talus articulates with the calcaneus at the subtalar joints that primarily allow the eversion and inversion action of the ankle and hindfoot.[8] Greater than 60% of the talus bone surface bears cartilage.[9] The superior aspect of the body of the talus articulates with the tibia, the lateral malleolus and medial malleolus, forming the ankle joint. The inferior aspect of the body of the talus and the lateral process interacts with the posterior facet of the calcaneus. The posterior process of the talus has medial and lateral tubercles that allow the flexor hallucis longus tendon to pass in between (figure 3). Anteriorly, the head of the talus articulates with the navicular, forming the talonavicular joint.[9] Talar fractures are a rare entity, accounting for only 1% of all lower extremity injuries.[10] Given the unique

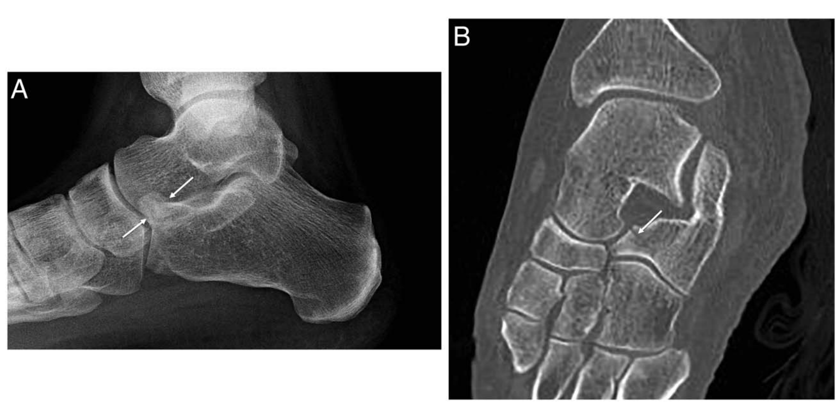

Figure 2 Anterior calcaneal process fracture. (A) Lateral foot radiograph with subtle cortical disruption of the anterior calcaneal process (arrows). (B) Coronal CT confirming virtually non-displaced anterior process fracture. Subtle cortical break and lucent, linear cortical disruption are present (arrows).

 Kiener AJ, *et al*. *Emerg Med J* 2016;**0**:1–7. doi:10.1136/emermed-2016-205706

Table 1 Sanders classification of intra-articular calcaneal fractures

	Description	Location modifier
Type I	Intra-articular fracture with <2 mm displacement	A Lateral
Type II	One primary fracture line	B Intermediate
Type III	Two primary fracture lines	C Medial
Type IV	Three or more primary fracture lines	

osseous and vascular anatomy of the talus, these injuries are associated with high morbidity.[10] Fractures of the talus can be categorised as below.

Neck and body fractures

Up to 45% of all talar fractures involve the neck. These are associated with high-impact injuries with hyperflexion of the foot and loading of the tibia, leading to impingement of the anterior tibia against the talar neck.[9] The Hawkins classification is used to classify talar neck fractures and has prognostic implications as shown in table 2. Hawkins 3 and 4 fractures are associated with higher rates of osteonecrosis.[9 11] Radiographic evaluation should include anteroposterior, mortise and lateral views of the ankle in addition to three views of the foot. An additional view called a Canale view has been described for the evaluation of talar neck fractures.[9 12] However, in our practice continued suspicion for acute talar neck fracture after normal standard radiographic views most often prompts evaluation with CT in the acute setting.

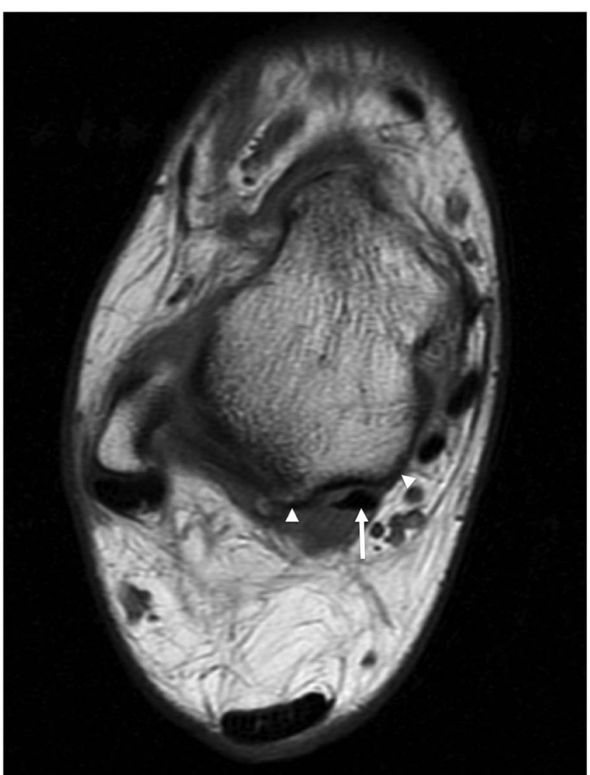

Figure 3 Normal anatomy. Axial T1-weighted MR image at the level of talus showing normal ankle flexor tendon anatomy with flexor hallucis longus tendon (arrow) interposed between the medial and lateral tubercles of the posterior talar process (arrowheads). The lateral tubercle is posterior, often more prominent, and easier to identify on lateral radiographs.

Table 2 Hawkins classification of talar fractures

	Description	Risk of AVN	Management
Type I	Non-displaced neck fracture with intact subtalar joint	10%	Closed reduction and immobilisation
Type II	Displaced neck fracture with subtalar joint subluxation/dislocation	30%	Close reduction with prolonged immobilisation or open reduction and internal fixation
Type III	Displaced neck fracture with separation of body from subtalar and tibiotalar joint	90%	Open reduction and internal fixation
Type IV	Subtalar, tibiotalar and talonavicular joint subluxation/dislocation	Variable; higher (30%) infection rate	Salvage treatment with methyl-methacrylate spacer

AVN; avascular necrosis.

Talar body fractures are typically due to axial loads. Because of the location of fractures, the tibiotalar joint and the subtalar joints are often involved.[9] Stranding in Kager's fat pad (located directly posterior to the tibiotalar joint) can alert the emergency provider to look closely for tibiotalar joint injury (figure 4). However, talar body fractures are often substantial injuries and readily evident on radiographs. Nonetheless, CT is often obtained for better delineation of fracture extent, given its increased sensitivity compared with radiographs alone.[13]

Lateral process fractures (snowboarder's fracture)

Lateral process fractures account for 25% of all talar fractures[11] and may occur in isolation or with other injuries. These fractures may be missed on initial radiographic evaluation, and because the clinical presentation is similar to common inversion ankle sprains, the clinical presentation may not provide the support necessary for advanced imaging. The lateral process articulates superolaterally with the fibula and inferomedially with the anterior aspect of the posterior calcaneal facet. The primary mechanism of injury is forced dorsiflexion and inversion of the foot causing the majority of force applied to the talocalcaneal joint to be centred laterally.[11] Fractures can be avulsion fractures, chip fractures or more extensive articular fractures and are classified by the revised Hawkins classification (not to be confused with the Hawkins classification of talar neck fractures).[11 14] Classification involves differentiating fractures into three groups: non-articular chip fractures, a single large fracture fragment involving both the talofibular and subtalar articulations, or a comminuted fracture involving both articulations. If the classification system is not used, corresponding description is important, as type 2 injuries (large fragment) may have better outcomes when repaired surgically. An AP mortise view of the ankle may be the only radiographic projection this fracture is visible on (figure 5). In the presence of soft tissue swelling inferior to the lateral malleolus, the lateral talar process should be closely interrogated. Additionally, a posterior subtalar effusion observed on lateral radiographs should raise radiographic suspicion for this injury. In a patient with the correct mechanism (inversion, dorsiflexion, axial loading) or history (snowboarding, skateboarding), CT may be useful to evaluate for radiographically occult injuries or determine the extent of the injury if one is seen.[9 11] As a note of caution, this should not be confused with the extensor digitorum brevis (EDB)

Figure 4 Talar body fracture. Lateral ankle radiograph (A) demonstrates soft tissue swelling anterior and posterior to the ankle joint. There is a cortical break (arrow) in the anterior talar body that was subsequently confirmed by CT as a comminuted talar body fracture. This fracture is not appreciated on the AP ankle radiographs (B) demonstrating the necessity of well-positioned lateral radiographs. (C) Kager's fat pad is the triangular region of fat posterior to the ankle joint and should be black by radiography. Here there is oedema in Kager's fat pad; when seen, the viewer should look very closely for fractures.

avulsion fracture, which is a crescentic avulsion fracture at the dorsolateral aspect of the calcaneus, involving the origin of the EDB. This fracture is best seen on a routine anteroposterior view of the ankle or dorsoplantar view of the foot (figure 6).

Posterior process fracture

Isolated fractures of the posterior process of the talus are rare. Fractures can occur in either the posteromedial or posterolateral tuberosity by various injury mechanisms, with fracture of the posterolateral tuberosity being more common.[11] These fractures are occasionally misdiagnosed as ankle sprains.[15] An acute fracture must be differentiated from an os trigonum, a normal anatomic variation with ossicle located posterior to the talus. A fracture line will be irregular, with sharp non-corticated margins (figure 7). A lateral radiograph provides a better assessment of the posterolateral tuberosity, while the posteromedial tuberosity is often best seen on an oblique externally rotated view. Radiographic findings of stranding in Kager's fat pad (at the posterior margin of the ankle joint) or an ankle joint effusion should increase the emergency care provider's degree of suspicion for this injury. CT or MRI should be obtained if clinical suspicion is high, with persistent pain and tenderness to palpation at the posterior aspect of the ankle joint, anterior to the Achilles tendon.

Osteochondral fracture

Osteochondral lesions of the talus (OLTs) are believed to result from transchondral fractures caused by tangential shearing force or repetitive microtrauma. These lesions are more common in males in the second decade and are commonly located along the medial or lateral edge of the talar dome. These injuries commonly occur following ankles sprains and reportedly present in up to 73% of ankle fractures.[16] There are no specific physical exam findings to differentiate these injuries from a sprain in the acute setting. Mechanisms of injury for OLT include inversion with dorsiflexion (for the anterolateral dome) and inversion with plantar flexion (for the posteromedial dome). The radiographic appearance of OLT depends on the severity as well as chronicity of injury, with acute lesions often being subtle. This necessitates detailed inspection of ankle radiographs on all views with close attention to the subchondral talar dome. Radiographic findings of OLT can vary from ankle joint

Figure 5 A 25-year-old man with lateral talar process fracture following a skateboarding accident. (A) AP ankle radiograph. Small bone fragment inferior to the lateral malleolus (arrowhead), and truncation of the lateral margin of the talus (arrow). A medial malleolus fracture is also present; (B) coronal CT. Comminution of the lateral process talus, which involves both the talofibular and the subtalar articulations (arrow). As in this case, CT findings are often more extensive than expected by radiography.

Figure 6 Extensor digitorum brevis (EDB) avulsion fracture and distal fibular avulsion fractures in the same patient. AP ankle radiograph (A) and AP foot radiograph (B) demonstrates tiny bony fragments at the inferior lateral margin of the hindfoot, along the dorsolateral calcaneal margin. These tiny bony flecks in this location, also seen on inset magnification images (B1) are characteristic of EDB avulsion, which occurs with forced inversion. This patient also had avulsion fractures from the fibular tip (circles).

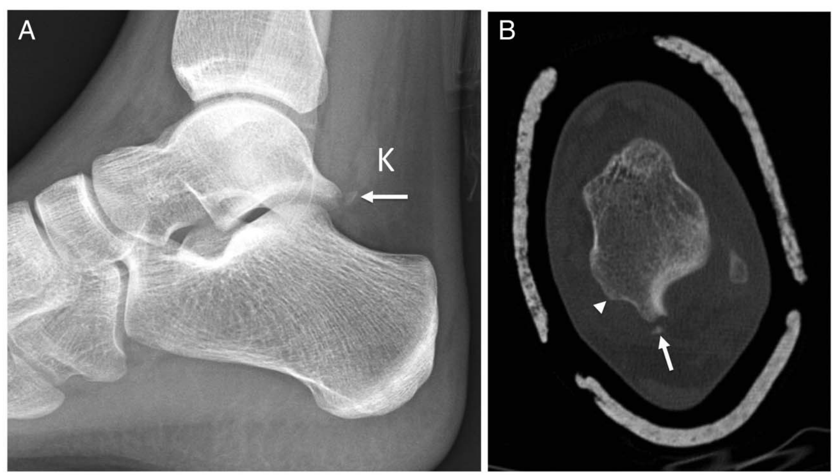

Figure 7 Posterior process talus fracture. A 15-year-old male status post sports injury. (A) Lateral radiograph. Bone fragment posterior to the lateral tubercle of the posterior process of the talus (arrow), with sharp margins and subtle donor site. Stranding is present in Kager's fat pad (K); (B) axial CT confirms fracture. Short medial tubercle is present (arrowhead), forming the groove for the flexor hallucis longus tendon.

Figure 8 Acute osteochondral lesion of the talus. A 32-year-old man with acute ankle pain following injury while playing basketball. (A) Oblique ankle radiograph showing subtle lucency at the talar dome (arrow); (B) coronal reformatted CT with subtle fracture and underlying lucency in the superolateral aspect of the talar dome (arrow); (C) fat-saturated proton-density-weighted MR image showing acute superolateral talar dome osteochondral lesion with subjacent oedema-type signal (arrow). The overlying cartilage also shows increased heterogeneous signal suggestive of acute injury.

effusion, subtle subchondral lucency, focal depression in the subchondral cortex or subchondral cystic change (figure 8). It is important to distinguish acute post-traumatic OLT from chronic subchondral cystic changes that are seen not too uncommonly on routine ankle radiographs or CT. Acute OLT on CT can be difficult to detect and may be seen as focal cortical depression

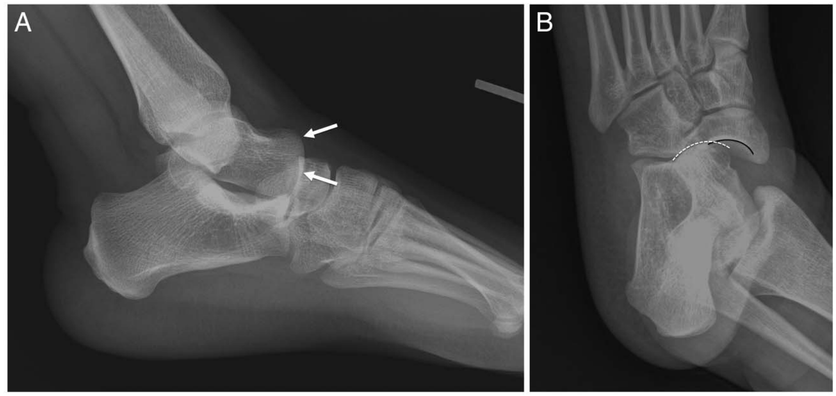

Figure 9 Talonavicular dislocation on lateral (A) and oblique (B) left foot radiographs. (A) Talar head (arrows) has dislocated dorsally with respect to the navicular fossa. (B) Talar head (dashed white line) is dislocated laterally with respect to the navicular fossa (solid black line).

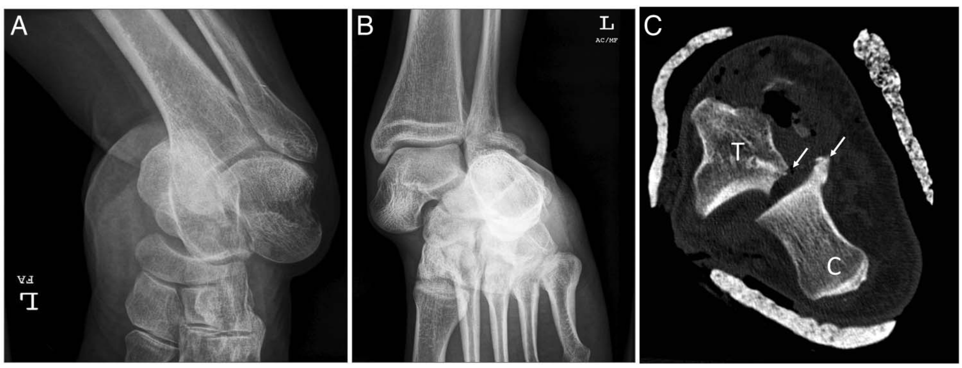

Figure 10 Subtalar dislocations. (A) Medial subtalar dislocation. The calcaneus is displaced medially to the talus and the talar head is directed laterally; (B) lateral subtalar dislocation. The calcaneus is displaced lateral to the talus, the talar head is directed medially and the foot is pronated; (C) separate patient with lateral subtalar dislocation. Axial CT centred at the posterior facet, shows lateral displacement of the calcaneus (C) with respect to the talus (T). Both the calcaneus and talus are fractured (arrows).

along the talar dome without cystic changes, whereas chronic lesions manifest as small cystic foci associated with sclerosis. Not uncommonly, MRI is performed as a problem-solving tool even if the radiographs and CT are negative if there is a high index of clinical suspicion. MRI remains the mainstay for detailed evaluation of the tibiotalar joint cartilage, lesion stability and planning future chondral reparative or restorative treatment.[17]

COMPLEX HINDFOOT INJURIES

The hindfoot is separated from the midfoot by the calcaneocuboid and talonavicular articulations, which act in unison and are commonly referred to as the transverse tarsal or *Chopart's* joint. The transverse tarsal joint is responsible for abduction and adduction of the foot.[18] In conjunction with the subtalar joint, the transverse tarsal joint allows tibial rotation to accompany forefoot pronation and supination. The transverse tarsal joint's stability is affected by the positioning of the subtalar joint.

Talonavicular dislocation

Talonavicular dislocations commonly occur with fractures to other tarsal bones. Talar fractures that result from axial loading, such as talar head fractures, put force on the articulation with the navicular.[9] If the force is severe enough, this can result in dislocation of the talonavicular joint (figure 9). Talonavicular dislocation can occur with cuboid, cuneiform and navicular fractures,[19 20] as well as in combination with fractures of the calcaneus.[21] This uncommon injury pattern is known as a transcalcaneal talonavicular dislocation. The AP or lateral radiographs are usually adequate for identifying talonavicular dislocation.[22] Depending on the injury identified by radiographs, a CT may be performed for further evaluation, often post-reduction to evaluate for fractures that are not evident or not well delineated on radiographs.

Subtalar dislocation

Subtalar dislocation is a biarticular dislocation comprising dislocation of the talocalcaneal and talo-navicular joints. It can be further classified by the direction of the dislocation, with medial dislocation occurring in 71% of cases, lateral in 26% of cases, and anterior and posterior being extremely uncommon[23] (figure 10). The mechanism of injury is usually considered to be high energy consistent with a motor vehicle accident or a fall from height, although it can also occur from lower trauma activities. Historically, there has been a male predominance of subtalar dislocations up to 9:1, but Hoexum and Heetveld[23] report it is more accurately around 3:1. CT is recommended to identify other fractures that may be occult by radiography and that may alter surgical management.[23]

Complete talar dislocation

Rare occurrence of this type of injury is owed to the deep location of the talus and the strong multifocal ligamentous attachments of its articulations. This type of injury is usually the result of a high-impact trauma and, as such, usually has accompanying fractures of the malleoli or talus.[24] A complete dislocation from the tibia, calcaneus and navicular without any fractures is even rarer and is estimated to account for only 2% of all talar injuries.[25] A complete talar dislocation is a severe injury with considerable morbidity due to the talus's role in connecting the distal leg to the foot.[25] Vascular supply and evaluation for avascular necrosis should be kept in mind since there is limited surface area for vascular perfusion as 60% of the talar surface bears articular cartilage.[9 26]

Competing interests FK is the American Roentgen Ray Society Scholar (2013–2016). FK also receives support from NIH Grant 1R56HL126558-01.

Provenance and peer review Not commissioned; internally peer reviewed.

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Emerg Med J published online March 3, 2016