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Osseous injuries of the foot: an imaging review. Part 2: the midfoot

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ABSTRACT
Injuries to the foot are a common cause for presentation to the emergency department (ED), 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 addressed forefoot injuries, Part 2 reviews midfoot injuries and Part 3 covers the hindfoot.

INTRODUCTION
Due to the complex anatomy of the midfoot and hindfoot, and resulting radiographic superimposition, fractures of the midfoot and hindfoot can be difficult to identify in the acute setting. This is particularly true in the polytrauma patient who may have suboptimal radiographic positioning. Thus, it is not surprising that these are among the most commonly missed of all fractures on preliminary clinical and imaging workup.[1] Patients with foot injuries will often present with non-specific pain, swelling and possible ecchymoses of the foot. These common presenting signs and symptoms underlie the importance of imaging in diagnosing the uncommon tarsal injuries.

Tarsal fractures and dislocations comprise less than 2% of all extremity injuries; however, due to weight-bearing stress on the tarsal complex, tarsal fractures are a significant cause of morbidity, particularly if the diagnosis is delayed.[2] [3] A detailed knowledge of imaging anatomy is essential for an accurate diagnosis of tarsal injury, and also to avoid common imaging pitfalls that may mimic acute osseous injury. This article reviews the anatomy of the midfoot as it relates to trauma radiology with a focus on identifying adult midfoot injuries, presented within the context of the three-column functional anatomy model of the foot.

The seven bones of the midfoot and hindfoot are collectively referred to as the tarsus (figure 1). The midfoot comprises the navicular and cuboid as well as the medial (C1), intermediate (C2) and lateral (C3) cuneiforms. The functional anatomy of the foot can be conceptualised as medial, middle and lateral columns. The medial column contains the talus, navicular, medial cuneiform (C1) and first metatarsal. The middle column includes the talus, navicular, middle (C2) and lateral (C3) cuneiforms and the second and third metatarsals. Finally, the lateral column is made up of the calcaneus, cuboid and fourth and fifth metatarsals. The medial and middle columns are less mobile than the lateral column but functions as a key structural support; in particular, medial column structure must be maintained in the post-traumatic setting. The lateral column acts as a semi-mobile weight-bearing beam, bearing body weight but with mobility that allows walking on uneven ground. Therefore, significant alterations in biomechanics occur with lateral column disruption and foreshortening. As such, maintenance of lateral column length is a core principle of treatment.

ISOLATED MIDFOOT INJURIES
Navicular
The navicular is involved in the medial and middle columns of the foot. The posterior articulating surface of the navicular with the talus (ie, talonavicular joint) is concave. The anterior surface of the navicular has three facets, each contacting one of the three cuneiforms and thereby forming the cuneonavicular articulation with mere gliding movement. The main role of the navicular is to support the medial side of the longitudinal arch and to transmit force from the subtalar joint to the forefoot.[4]

Navicular fractures
Isolated injuries of the navicular are rare because of its sheltered location. As such, these injuries usually occur in conjunction with other midfoot fractures or dislocations.[5] Injuries to the navicular will disrupt the stability of the medial column, but often also compromise the lateral column. The interaction of the two foot columns has been likened to that of the ring of the pelvis by DiGiovanni, explaining the tendency for the involvement of the opposite column.[5] Navicular fractures can be classified as avulsion, body or stress fractures (figure 2). Avulsion fractures are the result of low energy injuries with hyper-plantarflexion forces at the midfoot which disrupt the talonavicular ligament. Avulsion fractures can also occur involving the posterior tibial tendon or the spring ligament.[6] These fragments can be mistaken for accessory bones, but are distinguishable by fragment morphology, sharp-edged appearance on radiography and a history of trauma and point tenderness.[5] Higher energy trauma and crush injuries are more likely to result in fractures to the body, which can be divided into navicular body or tuberosity fractures.[5] Both body and avulsion fractures should be identified with anteroposterior(AP), oblique and lateral radiographs (figure 3). CT may be used for further investigation and surgical

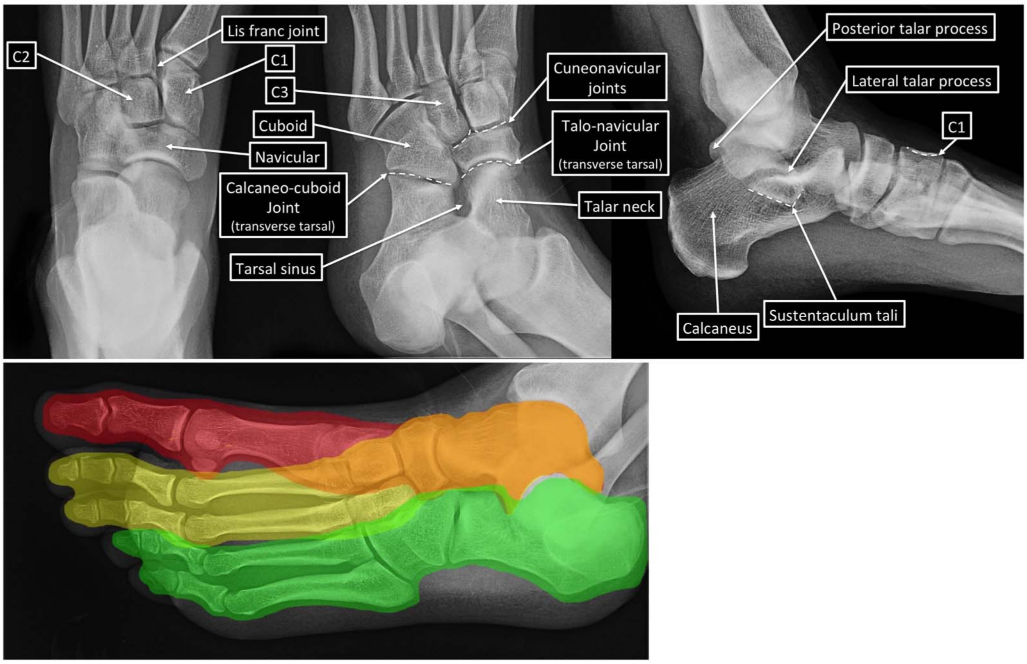

Figure 1 Top row: Anatomy of the hindfoot and midfoot on radiographs is hown. C1, medial cuneiform; C2, middle cuneiform; C3, lateral cuneiform. Bottom row: Coloured diagram delineating the three columns. Red is the medial column, yellow is the middle column and green is the lateral column. The shared structures of the medial and middle column are orange.

planning of known navicular fractures. CT is also useful for further evaluation of suspected navicular fractures in patients with negative radiographs.[5]

Navicular stress fractures are an increasingly common diagnosis.[7] Many studies have shown this injury occurring in athletes and other individuals who participate in physically demanding activities.[7–10] Repeated stress applied to the bone in activities like running leads to bone remodelling to meet the demands of this stress. When early osteoclast activity outpaces later osteoblast activity, a stress fracture can occur. Osteoporosis may also predispose a patient to these types of injuries, which have the appearance of stress fractures, but are more correctly called insufficiency fractures.[7] Radiographs can easily miss stress fractures, so clinical suspicion must be high; these injuries often manifest on radiographs as incomplete linear bands of sclerosis (see figure 2).[9 10] CT and MRI are gold standards to determine the presence of a stress fracture, but bone scintography may also be employed.[10]

Navicular dislocation

Isolated dislocation of the navicular is very rare.[11 12] It may occur in a neuropathic foot with muscular pull and failure of the ligaments holding the bone in place. This will result in a medial and plantar displacement. Acute trauma with hyperplantarflexion and axial loading can lead to dorsal displacement of the bone.[12] Standard radiographs of the midfoot easily identify these dislocations, with an empty navicular fossa seen on lateral views.[13]

Cuneiform

The medial, intermediate and lateral cuneiform come in contact with the first three metatarsal and are involved in the medial and middle columns of the foot.

Cuneiform fractures

Isolated cuneiform fractures are extremely rare and account for only 1.7% of all tarsal fractures.[14] They are commonly seen in

Figure 2 Images showing navicular injuries. (A) Acute navicular fracture on anteroposterior radiograph (arrow); (B) acute comminuted navicular fracture on plantar flexion positioning coronal CT (arrow); (C) linear lucency anteromedial navicular rimmed by sclerosis, compatible with stress fracture (arrow) are shown. This stress fracture is in an atypical location, but with a classic radiographic appearance.

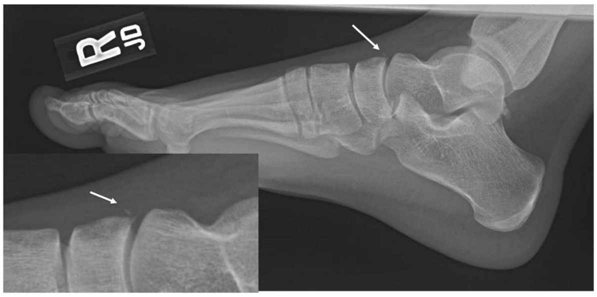

Figure 3 Lateral foot radiograph and inset magnification image demonstrating an acute dorsal navicular avulsion fracture (arrow) in a patient who reported twisting of ankle while walking. The patient had focal tenderness to palpation in this location. Notice the typical appearance of a very thin avulsed slip of bone.

Table 1 Myerson classification of Lisfranc fracture-dislocations

Incongruity	Subtype	Description
Type A		
Complete		Dislocation of M1–M5 in the same direction (either lateral or dorsoplantar)
Type B		
Incomplete	B1	Medial dislocation involving only the M1 joint
	B2	Lateral dislocation involving any of the M2–M4 joints
Type C		
Incomplete/ complete	C1	Divergent, incomplete dislocation involving M1 and *some* of the lateral metatarsals
	C2	Divergent, complete dislocation involving M1 and *all* of the lateral metatarsals

combination with tarsometatarsal (TMT) joint injuries.[12] Only a handful of case reports of isolated cuneiform fractures are present in the literature[15] (figure 4). Mechanisms of these fractures are usually due to significant amounts of force as an indirect axial load[12] or due to crush injuries to the midfoot.[14 16] These fractures can be detected on standard foot radiographs with careful examination, but CT is useful in confirming the presence of a cuneiform injury, evaluating fracture extent, and also identifying additional fractures which may be occult by radiography.[12]

Cuboid

On the lateral side of the midfoot lies the cuboid, which is part of the lateral column of the foot. The cuboid articulates with the calcaneus along the posterior surface and is important in maintaining the arches of the foot. The calcaneocuboid articulation is robust due to the stabilising ligamentous attachments as well as the relationship to the peroneus longus tendon, which runs along the inferior surface of the cuboid.[4 17] The facets of the cuboid that contact the lateral surfaces of the navicular bone and the lateral cuneiform are relatively flat and allow for gliding motion in multiple directions.[18]

Cuboid fractures

Isolated fractures of the cuboid are rare and there is limited literature describing them. These fractures have been termed 'nutcracker fractures', as the cuboid is compressed by axial loading force, which transmits through the calcaneus along the lateral column. Cuboid fractures are often associated with other fractures and dislocations of the midfoot.[19–21] Standard radiographs may delineate the cuboid fracture itself depending on the degree of displacement or show shortening of the lateral column.[20] CT is indicated in these cases due to the high incidence of associated fractures as well as Chopart and Lisfranc dislocations.[19] Fragmentation of the cuboid may shorten the lateral column, which necessitates fixation.

COMPLEX MIDFOOT INJURIES

The midfoot articulates with the forefoot at the TMT joints, also referred to as the Lisfranc joint. This joint includes the five metatarsals, three cuneiforms and the cuboid. The stability of this joint results from the interlocking structure and arch-like organisation of these bones. The second metatarsal (M2) base acts as the keystone in the transverse arch of the foot. The M2 base provides stability to the midfoot because it articulates with the flanking C1 and C3 cuneiforms, in addition to a broader articulation with C2.[22 23] This anchors the metatarsals securely to the midfoot. Important ligaments such as the Lisfranc ligament, which runs obliquely and connects C1 to M2, also play a role in maintaining the Lisfranc joint and the connections of the midfoot to the forefoot.[23]

Lisfranc fracture-dislocations

Injury to the TMT joint resulting in a Lisfranc fracture-dislocation is most commonly due to high-energy trauma.[23] Low-energy trauma can cause injury to the joint, but these are called Lisfranc injuries, or referred to as midfoot sprains. Lisfranc fracture-dislocation is due to direct force applied to the joint and is often associated with other injuries to the foot in addition to involvement of the Lisfranc ligament (which connects the medial cuneiform to the second metatarsal).[23] Different classification systems exist but the most commonly used is the Myerson system, which expands off of the Quenu and Kuss system set forth in the early 20th century. The Myerson system has a good degree of interobserver reliability, and is reviewed in table 1.[23] Close interrogation of all three views is necessary when there is clinical concern for Lisfranc injury. On the oblique view, the base of the first and second

Figure 4 Image showing cuneiform fractures in a 32-year-old male. (A) Magnified oblique radiograph with very subtle lucencies and trabecular disruption involving C1 and C2 is shown; (B) coronal CT confirms cuneiform fractures (arrow) as well as fracture of the second metatarsal base.

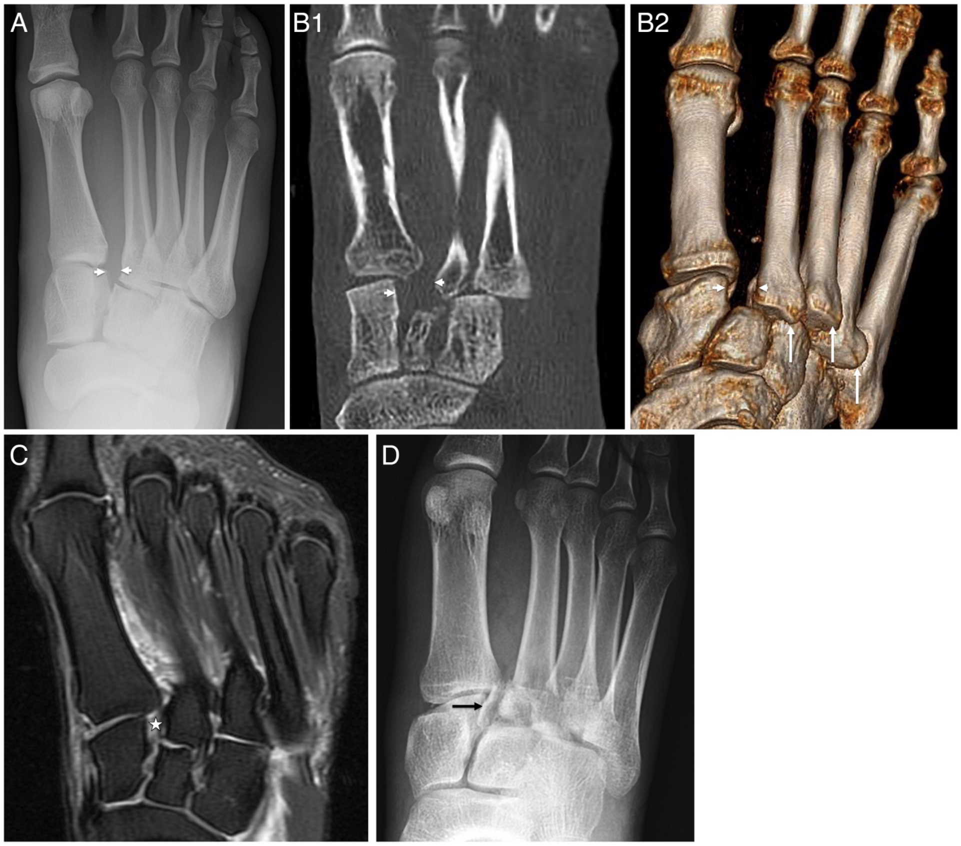

Figure 5 Lisfranc injury. Thirty-four-year-old male with pain following trauma. (A) Anteroposterior foot radiograph showing mild widening of the C1–M2 interspace (arrowheads) with incongruence at the second metatarso-phalangeal joint, suspicious of Lisfranc ligament injury. (B) Reformatted axial CT with volume rendering showing widened C1–M2 interspace (arrowheads). Volume rendered reformat demonstrates dislocation of the second, third and fourth metatarsal bases (arrows). (C) Axial fat-saturated proton-density-weighted image showing torn Lisfranc ligament in mid-segment with associated soft tissue oedema in the first–second intermetatarsal space (star). (D) Different patient (36-year-old male) with Lisfranc injury including fracture at the base of the of second metatarsal, *fleck sign* (arrow).

metatarsals should align perfectly with C1 and C2 respectively. Any concern for misalignment warrants further evaluation with weight-bearing views (dorsoplantar and lateral), during which normal physiological stress of body weight can exaggerate metatarsal–cuneiform misalignment or reveal widening of the distance between the second metatarsal base and C1 (which is the space that the Lisfranc ligament spans).[24] The AP view is best for evaluating C1–M2 or M1–M2 widening, and greater than 2 mm displacement of the medial cuneiform from the base of M2 can be seen along with a possible 'fleck sign' which indicates damage to the TMT joint[22 23] (figure 5). This 'fleck sign' represents a chip of either C1 or M2 and is present in 90% of Lisfranc injuries and has been called pathognomonic for Lisfranc fracture-dislocations.[25] Additionally, as discussed in Part 1, fractures near or involving the metatarsal bases should prompt close examination for Lisfranc injury. Weight-bearing radiographs should be performed if the initial images are negative. CT, MRI or bone scintography can also be performed if the radiographs are still inconclusive.[23]

Complex and crush injuries

Crush injuries and other high-energy trauma mechanisms often result in multiple fractures and dislocations of tarsal and metatarsal bones. It is important in such settings to carefully delineate all injuries, allowing the orthopaedist to develop an appropriate treatment strategy. Subsequent radiographs performed after initial reduction or realignment of the most overt injuries may allow visualisation of other fractures, which were initially occult. Foot compartment syndrome is a severe complication of this type of trauma. This syndrome occurs when increased pressures within an anatomical compartment, often as a result of oedema and/or inflammation, can jeopardise vascular flow and neural input to the structures passing through that region. In fact, crush injuries to the mid-foot are the most common aetiology of foot compartment syndrome.[26] It has been reported following calcaneal, peritalar, midtarsal and metatarsal fractures in addition to Lisfranc fracture-dislocations.[27]

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