Seminars in
ROENTGENOLOGY

Foot and Ankle Disorders: Radiographic Signs

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The foot and ankle are commonly imaged for a variety of pathologies ranging from traumatic, degenerative, inflammatory, neoplastic, and others. Over the past two decades, emphasis in radiology has been directed toward "advanced" imaging, primarily computed tomography (CT) and magnetic resonance imaging (MRI), to an extent where radiographic findings may be overlooked or ignored. Imaging assessment should virtually always commence with radiographs. A thorough knowledge of the radiographic anatomy, biomechanics, and radiological signs of pathology is critical for accurate imaging interpretation; recognition of these findings on radiographs may obviate the need for additional imaging expense and can lead to more accurate interpretations of advanced imaging exams when acquired.

The foot is divided into three anatomic zones: the hindfoot, midfoot, and forefoot. The hindfoot consists of the talus and calcaneus, which is separated by Chopart's joint (talonavicular and calcaneocuboid joints) from the midfoot (the remaining tarsal bones). The midfoot, in turn, is separated from the forefoot (metatarsal and phalanges) by the tarsometatarsal (Lisfranc) joint.

Radiographic interpretation should begin with evaluation of the soft tissues and osseous alignment. Soft tissues are a window to underlying osseous pathology and detection of soft-tissue swelling or joint effusion can help focus the interpreter's eye to subtle osseous abnormalities. Similarly, subtle malalignment can indicate significant injury. Table 1 summarizes the radiographic analysis of every radiograph of the ankle and foot.

Radiographic Views

Radiographic Evaluation of the Ankle

A routine radiographic evaluation of the ankle includes a lateral view (to include the fifth metatarsal base), an anteroposterior view, and a "mortise" view. On the AP view, the tibiotalar joint (the mortise) is partially overlapped by the fibula; the mortise view is obtained by positioning the ankle with approximately 15 to 20° of internal rotation (to align the medial and lateral malleoli parallel to the tabletop). The result is an unobscured view of the talar dome and plafond (the tibial and fibular "roof" of the joint).

Other views may be useful to answer specific questions. For example, a Harris–Beath (skier's) view, an axial oblique view through the calcaneus with the foot dorsiflexed, provides an additional projection through the posterior calcaneal tubercle and sustentaculum tali (which can be useful, for example, in the setting of suspected fracture); the radiograph beam also projects tangentially through the posterior and middle facet of the subtalar joint (which can be useful for evaluation of subtalar coalition or arthritis). The Canale view, helpful for evaluating oblique talar neck fractures, is obtained by placing the ankle in maximal plantar flexion, pronating the foot approximately 15°, and angling the x-ray tube 75° from the horizontal with the beam directed cephalad.

Radiographic Evaluation of the Foot

A basic evaluation of the foot should start with an anteroposterior and lateral view (including the entire foot and ankle). With the exception of trauma, these views should be acquired with weight-bearing if the patient can tolerate; this helps standardize the views and provides biomechanical information, revealing subtle malalignment and true deformities. Internal and external oblique views are very useful as supplementary views; because the tarsal bones and metatarsals are arranged in an arch configuration, a single AP view results in overlap of these structures. An external oblique view, for example, optimally visualizes the lateral aspect of the midfoot and is particularly valuable for evaluation of calcaneonavicular coalition.

A sesamoid view is acquired with the beam directed anteroposteriorly with the foot plantarflexed and the toes pulled back into a dorsiflexed position. A single toe can be dorsiflexed to acquire oblique or lateral views of one digit.

Basic Anatomy and Alignment

The ankle is composed of the talocrural (tibiotalar) and subtalar (talocalcaneal) joints. The tibiotalar joint is surrounded

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doi:10.1053/j.ro.2005.01.018

Table 1 Radiographic Analysis of the Ankle and Foot

Ankle joint 3-4 mm in width
Medial clear space 3-4 mm
Lateral clear space 5 mm
Tibiofibular syndesmosis should have slight overlap
Soft-tissue swelling
Ankle effusion
Pre-Achilles triangle or Kager fat pad
OCD: talus, tibial plafond, navicular
Subtalar joint
Calcaneonavicular coalition [anteater nose sign]
Talocalcaneal coalition [complete C-sign]
Anterior process of calcaneus
Check base of fifth metatarsal for Jones fracture
Medial aspect of 2nd metatarsal aligns with medial aspect of middle cuneiform

by a capsule, which, when distended anteriorly by a joint effusion results in a teardrop density[1] (Fig. 1). The presence of ankle effusion in the context of acute trauma should prompt diligent evaluation to exclude a fracture. An ankle effusion with total capsular distension (anterior and posterior) greater than 13 mm has an 82% positive predictive value for an occult fracture.[2] However, subcutaneous edema at the lateral malleolus can overlap the anterior ankle joint on a lateral view and simulate a joint effusion. More superiorly, disruption of the inferior tibiofibular syndesmosis is implied by joint separation by more than 4 mm. However, rather than relying on a measurement which can vary depending on patient size, the medial and lateral tibiotalar joint recesses should be compared. If there is asymmetry of the joint space in the setting of injury, syndesmosis disruption should be suspected (Fig. 2A).

Calcaneal Inclination

Calcaneal inclination is the angle between the ground and the inferior aspect of the calcaneus (normally 18 to 22°). If the calcaneus is tilted upward distally it is referred to as "pes cavus" or "equinus" position; horizontal orientation is referred to as "pes planus" or "calcaneus" position. Pes planus is often associated with hindfoot valgus and overpronation with posterior tibial tendon dysfunction (Fig. 2B). Pes planus is also associated with plantar fasciitis. Pes cavus may also result in Achilles tendon pathology.

Valgus/Varus

The angle between the talus and calcaneus is normally 35 to 50° on a standing lateral view and 17 to 20° on a standing AP view of the foot. Valgus in general describes a situation in which the distal bone (in this case the calcaneus) is deviated laterally. Therefore, in hindfoot valgus, the calcaneus is lateralized relative to the talus; the talocalcaneal angle is increased on both lateral and AP foot views, and there is often overpronation and pes planus. Hindfoot valgus may be seen in coalitions as well as PTT dysfunction. In severe PTT dysfunction, the calcaneus may tilt so far laterally that it abuts the fibula (calcaneofibular abutment). Conversely, in hindfoot varus, seen in clubfoot deformity (talipes equinovarus), the talus and calcaneus are aligned more parallel on all views.

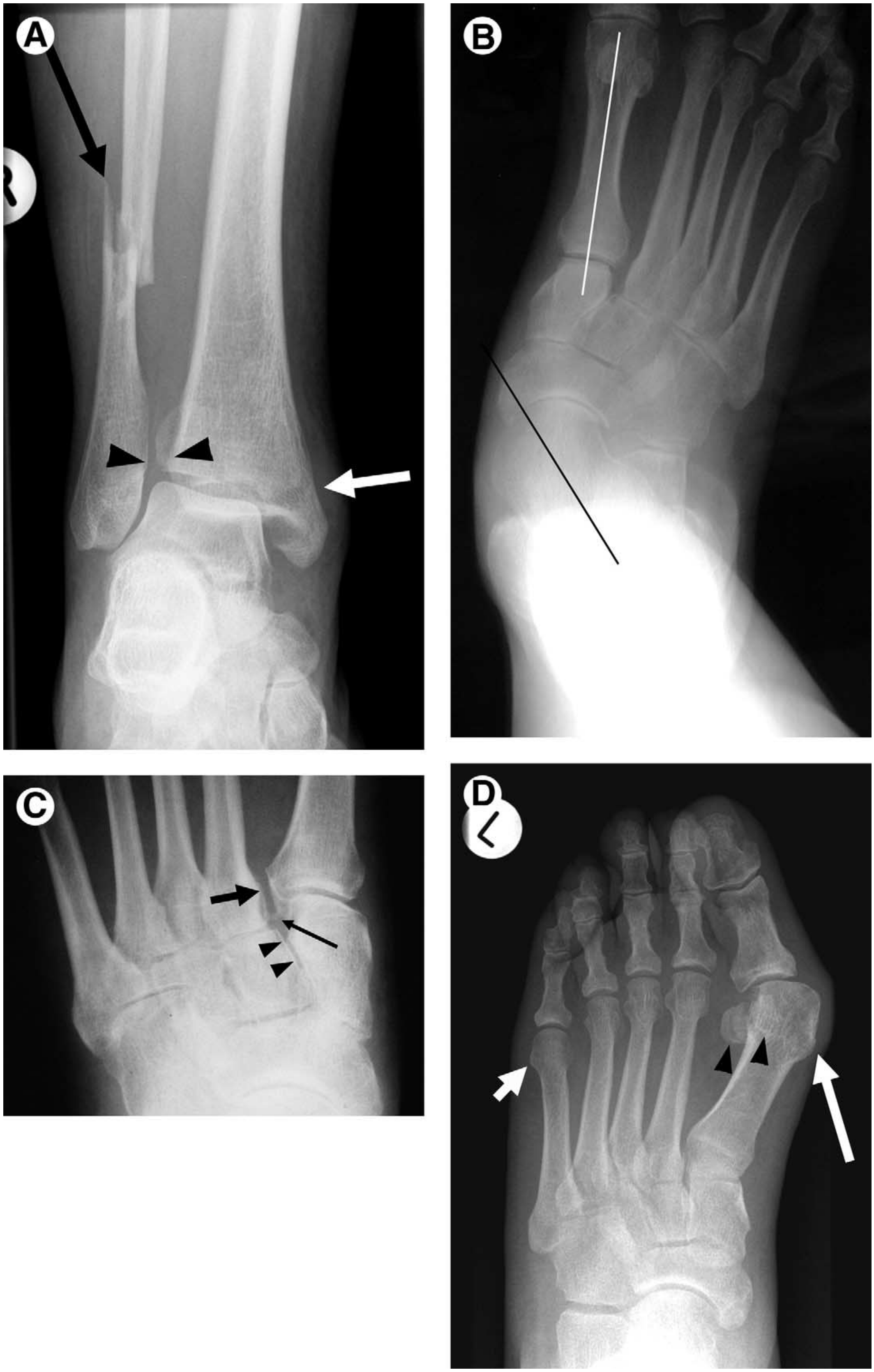
Pronation/Supination

Pronation and supination of the foot is analogous to that of the hand. If you consider the plantar aspect of the foot is equivalent to the palm, in pronation, the bottom of the foot is turned outward, and in supination, it is turned inward. The talus points into the ground instead of being aligned with the first metatarsal shaft (Meary's angle). This has been described as an increase in "talar declination angle," resulting in depression of the medial longitudinal arch. Pronation is also seen in the setting of pes planus, and people with this anatomy developmentally are susceptible to plantar fasciitis. Acquired overpronation (Fig. 2B) is seen in the setting of posterior tibialis tendon dysfunction, in which hindfoot valgus and forefoot abduction is also seen.

Lisfranc Alignment

A number of ligaments, as well as the configuration of the surrounding bones, stabilize the Lisfranc joint. The second metatarsal base is inset within the tarsal bones relative to the other metatarsals; its medial aspect should align precisely with the second cuneiform (Fig. 2C). The metatarsal bases form a transverse arch, with the second metatarsal base, having a "keystone" shape, providing stability to the midfoot similar to a Roman arch. The second metatarsal is kept in

Figure 1 Ankle joint effusion. Lateral view of the ankle shows opacity (arrows) anterior to the ankle joint consistent with effusion. A large effusion is often seen in the setting of fracture. However, soft-tissue swelling over the lateral malleolus can overlie the anterior ankle and simulate an effusion.


A
R
B
C
D

place primarily by the Lisfranc ligament, which extends obliquely to the first cuneiform. Therefore, this ligament has a great deal of importance in stabilization of the midfoot. If the Lisfranc ligament is torn or avulsed (due to trauma or neuropathic disease), the second metatarsal subluxes laterally and dorsally, often in concert with the other metatarsals.

Metatarsal Alignment

The metatarsal bones are normally aligned in a fairly parallel orientation. Medial deviation of the first metatarsal bone is also known as "metatarsus primus adductus (or varus)", occurring when the first intermetatarsal angle is 12° or more. This is associated with hallux valgus and bunion deformity (Fig. 2D). Similarly, lateral deviation or bowing of the fifth metatarsal bone can result in a "bunionette" deformity or bone proliferation at the lateral aspect of the fifth metatarsal head.

The alignment of the metatarsal heads creates a parabola, which is important for equalizing plantar pressures during push-off. If this alignment is altered developmentally (eg, long second metatarsal, or "Morton foot"), traumatically (eg, dorsal or plantar angulation of a metatarsal fracture), or surgically (eg, shortening of the first metatarsal after hallux valgus repair), then the result can be a variety of stress or friction-related pathology including callus, bursitis, stress fracture, osteoarthritis, and avascular necrosis.

Hallux Valgus

Hallux valgus is lateral angulation of the great toe relative to the first metatarsal shaft. Although this angle may be measured, it can be useful to gauge severity based on associated bowstringing of the flexor hallucis longus tendon with lateralization of the sesamoids (Fig. 2D). Normally, the sesamoids are centered under the first metatarsal head on the AP standing view of the foot; in hallux valgus they become subluxed laterally and erode the crista, a central prominence at the inferior margin of the first metatarsal head that creates facets for the sesamoids. A sesamoid view can be useful for depiction of this process. Secondary osteoarthritis of the first metatarsophalangeal joint and metatarsal-sesamoid joints is common. Hallux valgus is often associated with an increased first intermetatarsal angle, also known as "metatarsus primus adductus." This configuration can lead to bunion formation, with bone proliferation at the median eminence, cystic change, and overlying callus and bursitis.

Ankle Fractures: Mechanism and Injury Pattern

The Lauge–Hansen classification of ankle fractures remains the most commonly used method of describing ankle fractures and is dependent on the morphology of the fibular fracture. Avulsion fractures are usually transverse and impaction fractures assume an oblique or spiral appearance. Designation is given to the position of the foot (whether it is supinated or pronated) and the rotation of the talus (possibilities including external rotation, adduction, and abduction). The original position of the foot determines which component is under stress first, with further stress resulting in a predictable pattern of injury according to the direction of the force. Thus, by being aware of the relevant biomechanical stressors, accurate classification and appropriate treatment is possible. Familiarity with the pattern of injury and the mechanism involved allows for a careful search for occult injuries (osseous or ligamentous) not immediately apparent.

Supination-External Rotation (SER) Injury

This is the classic "inversion" injury (Fig. 3A). SER fractures account for 60% of ankle injuries.[3] In the supinated foot, the deltoid ligament is relaxed, with taut lateral ligaments. When an external rotatory force is applied, the talus impacts the fibula. At the lower end of the spectrum, this results in disruption of the tibiofibular ligament (SER-1) or a Tilleaux fracture (Salter–Harris type 3 fracture of the anterior lateral tibia). With further rotation, an oblique or spiral anteromedial fracture of the fibula occurs at the level of the mortise, extending superolaterally (SER-2). With an SER-3 injury, avulsion of the posterior tibial lip occurs. Finally, if the external rotatory force is of sufficient magnitude, an SER-4 injury results in an avulsion fracture of the medial malleolus due to forces imparted by the originally relaxed deltoid ligament.

Figure 2 Malalignment. (A) Syndesmosis disruption. Frontal view of the ankle shows a transverse medial malleolar fracture (short arrow) and fibular shaft fracture (long arrow) compatible with an eversion mechanism. Note widening of the distal tibiofibular syndesmosis (arrowheads) consistent with ligamentous disruption. (B) Overpronation in posterior tibialis tendon dysfunction. AP view of the foot shows the orientation of the talus (black line) directed medial to the forefoot; normally this line intersects the first metatarsal shaft (white line). This indicates overpronation and is seen in the setting of posterior tibialis tendon dysfunction, often associated with pes planus and arch collapse. (C) Lisfranc injury. AP view of the midfoot shows widening of the interval between the first and second metatarsal bases with offset of the medial edge of the second metatarsal (short arrow) compared with the medial margin of the second cuneiform (arrowheads) consistent with Lisfranc ligament injury. Note small avulsion (long arrow). (D) Hallux valgus and bunion. AP view of the foot shows hallux valgus with bone proliferation at the median eminence (bunion deformity, long arrow) with lateral subluxation of the sesamoid bones (arrowheads). Note also mild bone proliferation at the lateral aspect of the fifth metatarsal head (short arrow) representing a bunionette. There is also abnormal widening of the angle between the first and second metatarsal shafts (metatarsus primus adductus).

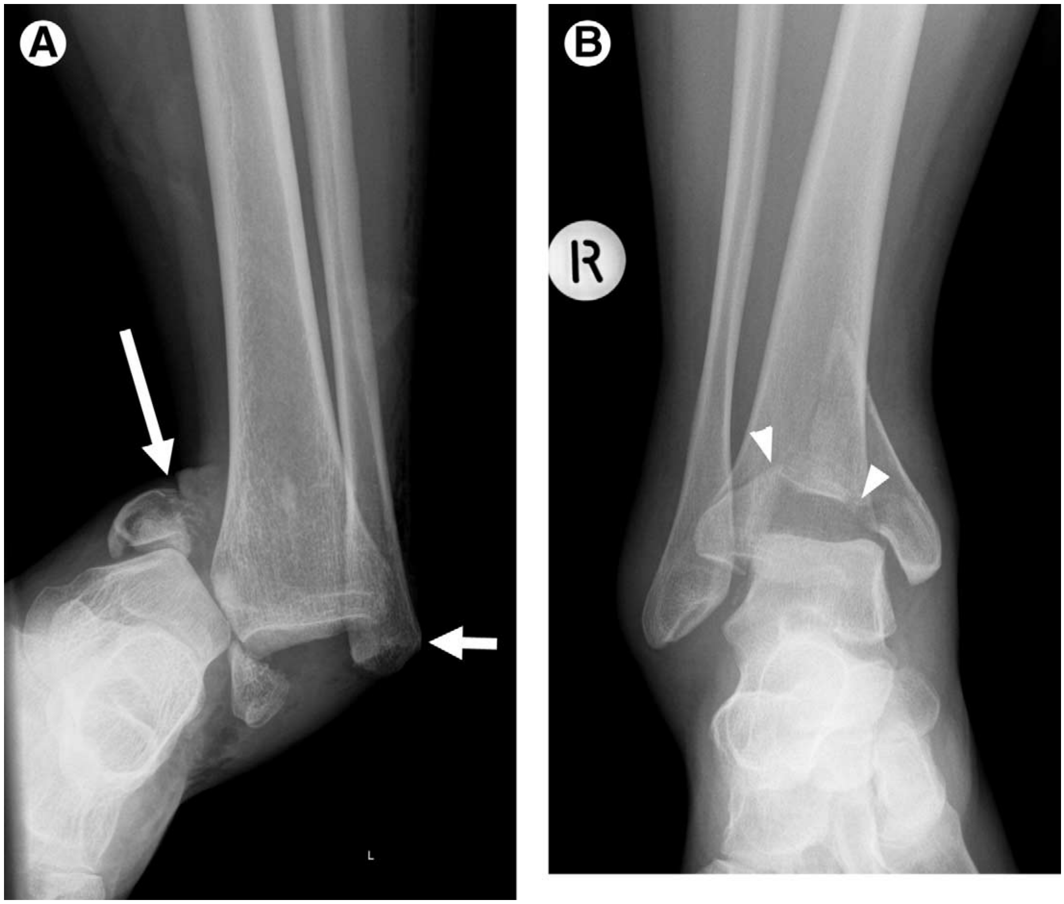


Figure 3 Ankle fractures. (A) Inversion injury. Transverse fracture of the distal fibula (short arrow) is consistent with avulsion stress and inversion mechanism, as is the oblique fracture of the medial malleolus (long arrow). High force load has resulted in ankle dislocation. (B) Pilon fracture. Comminuted fracture involving the distal tibial articular surface (arrowheads) representing a pilon fracture.

Supination-Adduction (SAD) Injury

As for the supination-external rotation injury, the ankle is originally in the supinated position (relaxed deltoid ligament and tight lateral ligamentous complex). With adduction of the talus, the lateral collateral ligaments are disrupted, or alternatively, a *transverse* (avulsion) fracture of the lateral malleolus occurs (SAD-1). Further adduction forces result in impaction of the talus with the medial malleolus, resulting in an oblique, near vertical fracture (SAD-2). The injury accounts for 20% of ankle fractures.

Pronation-External Rotation (PER) Injury

This is the classic "eversion" injury (Fig. 2A). In pronation, the deltoid ligament is taut. Thus, external rotation ruptures this ligament or produces a transverse (avulsion) fracture of the medial malleolus (PER-1). Disruption of the anteroinferior tibiofibular ligament and the interosseous membrane causes diastasis, compounded by the talus rotating against the lateral malleolus (PER-2), thus separating the malleoli. A spiral (Dupuytren) fracture of the fibular shaft, some 8 cm above the ankle joint, occurs with further force (PER-3). Finally, as for SER injuries, additional forces cause a posterior lip fracture (PER-4).

Pronation-Abduction (PAB) Injury

The first two stages (PAB-1 and PAB-2) are indistinguishable from the two stages of PER injuries. In PAB-2, both the anterior and the posterior tibiofibular ligaments are disrupted. The PAB-3 injury results in a short oblique and often comminuted supramalleolar fibular fracture.

Pronation-Dorsiflexion (PDF) Injury

This is a rare injury, the result of axial compression forces. Initially, a transverse fracture of the medial malleolus occurs (PF-1), followed by an anterior tibial lip fracture (PDF-2). With ongoing dorsiflexion, a supramalleolar fibular diaphyseal fracture (PDF-3) and, finally, a posterior transverse tibial fracture (PDF-4), result.

Other Ankle Fractures

Pilon Fracture

Pilon fractures are typically due to axial load across the ankle, resulting in a comminuted, intraarticular distal tibial fracture (Fig. 3B). Often these are a result of a high-energy mechanism such as a motor vehicle accident, and penetration through

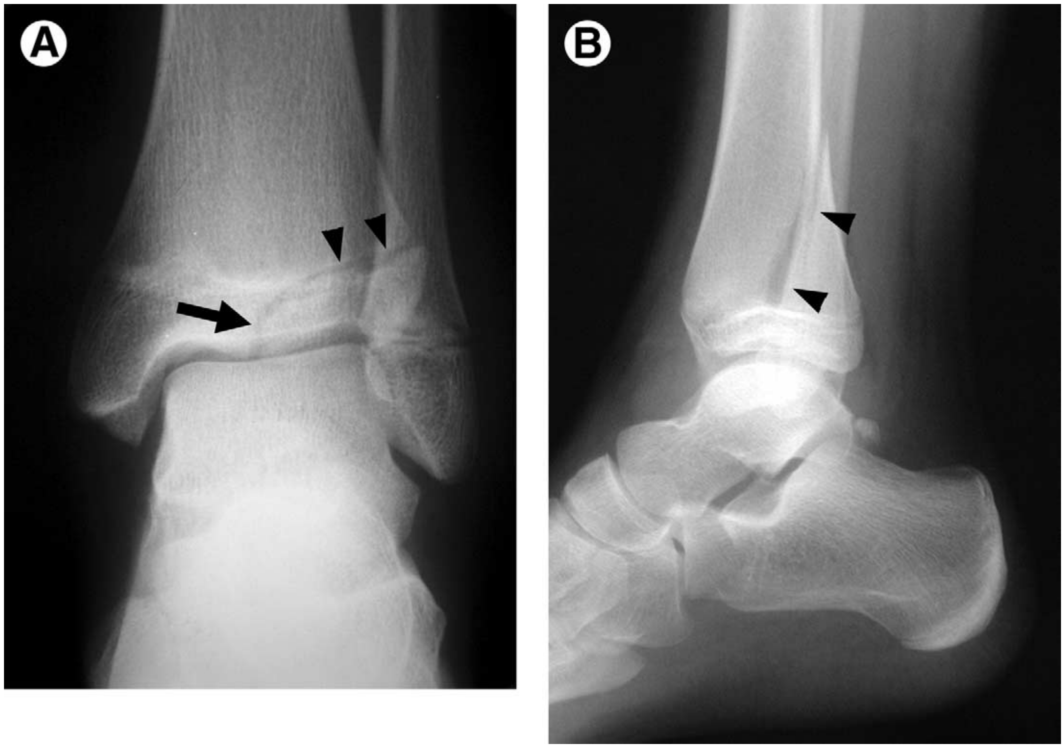


Figure 4 Tilleaux and Triplane Fracture. (A) Tilleaux fracture. AP view of the ankle shows a vertically oriented fracture line (arrow) through the distal tibial epiphysis, with widening of the lateral physeal plate (arrowheads) representing a Salter 3 injury of the anterolateral aspect. (B) Triplane fracture. Lateral view of a different patient shows a coronally directed metaphyseal fracture of the distal tibia (arrowheads). When in combination with transverse physeal plate disruption and a sagittally oriented epiphyseal fracture (as seen in A), this Salter 4 injury is referred to as a triplane fracture.

the skin (open fracture) and associated fibular fractures are common. Classification into three types is based on the degree of comminution and articular disruption.

Tilleaux Fracture

An uncommon avulsion fracture of the anterior lateral tibial margin, the Tilleaux fracture, originates from the anterior syndesmotic ligament and extends horizontally along the epiphysis, turning 90° vertically to the articular surface. If the physeal plate is open (Fig. 4A), this becomes a Salter–Harris type 3 injury ("juvenile Tilleaux fracture").

Triplane Fracture

The triplane fracture is like a juvenile Tilleaux fracture that extends to the posterior tibial metaphysis (Fig. 4B). As the name implies, this is a complex injury, with components in three different planes: a horizontal fracture through the lateral tibial physeal plate, a vertical fracture in the sagittal plane through the epiphysis (similar to the Tilleaux fracture), and additionally, a vertical fracture in the coronal plane through the posterior tibial metaphysis. Thus, the injury is a Salter–Harris type 4 injury and is usually secondary to a plantar flexion injury combined with external rotation.

Maisonneuve Fracture

The Maisonneuve fracture is a high fibular fracture, secondary to transmission of traumatic forces along the interosseous membrane. When a transverse fracture is seen through the medial malleolus implying an eversion injury, and there is suspected widening of the syndesmosis, the assumption must be that the force has extended up the interosseous membrane and imaging of the proximal fibula should be performed.

Fractures Associated with Ankle Sprain

Malleolar Avulsions

When radiographs are obtained following a severe sprain, lateral malleolar avulsion fractures are common, usually originating from the attachment of the anterior talofibular ligament. Medial malleolar fractures arising from the deltoid ligament are much less common. The acute avulsion fracture is seen as a thin, sharp cortical fragment, with surrounding soft-tissue swelling. On healing, the fragment may attach to the underlying bone, resulting in a small exostosis, or may remain displaced and become rounded. Injured ligaments may also ossify during healing and can result in multiple rounded calcified foci adjacent to the malleoli in patients with remote injury. Although much attention is spent detecting malleolar avulsion fractures, they are not treated differently than a severe sprain. Their detection, as with any fracture, should merely intensify the search for other fractures.

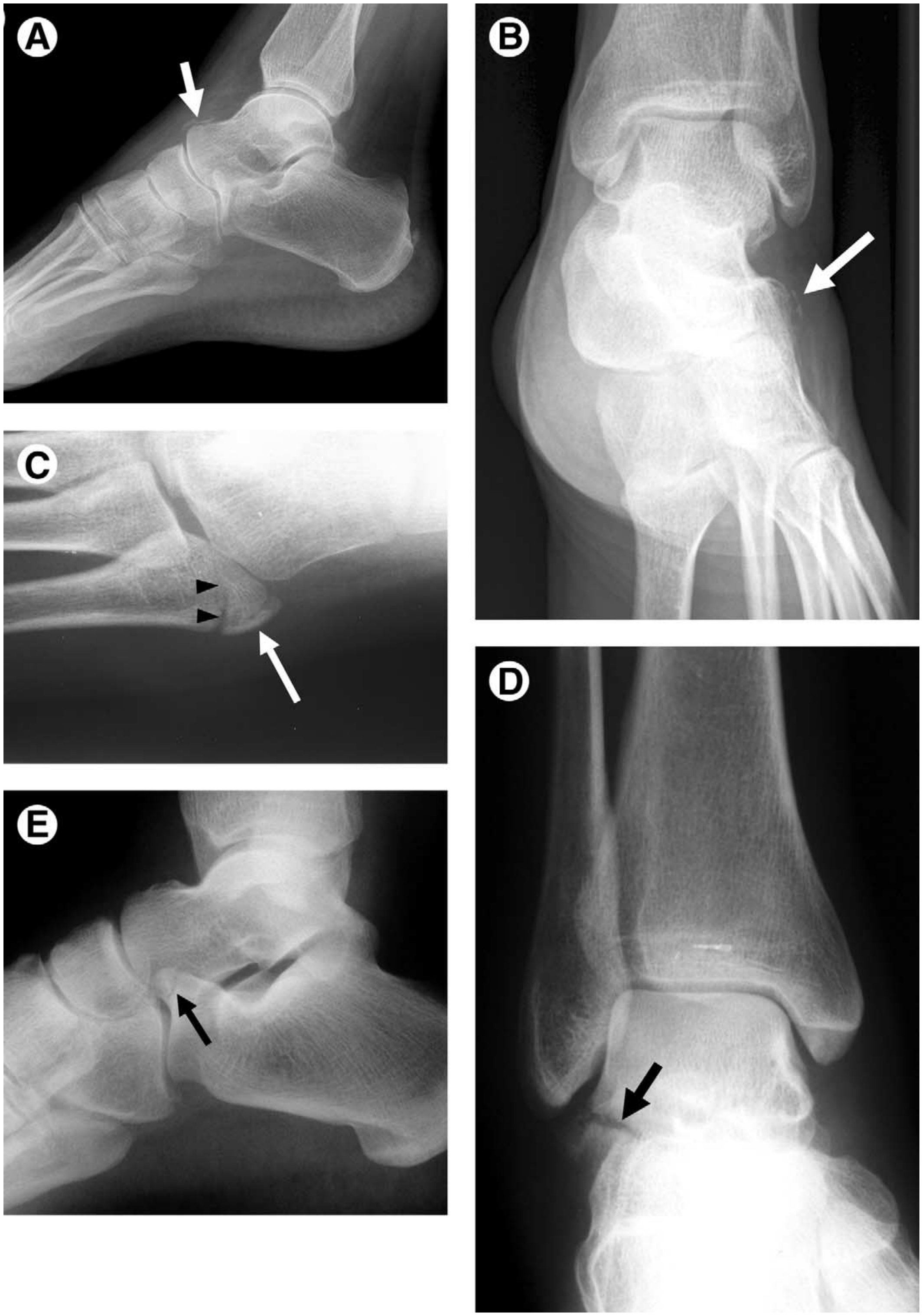


Figure 5 Fractures associated with ankle sprain. Avulsion fractures, particularly at the lateral malleolus, are common in the setting of ankle sprain. Occasionally overlooked are sites of other fractures, including the following. (A) Dorsal capsular avulsion. Lateral view of the foot demonstrates a curvilinear calcification dorsal to the talar head (arrow) representing a capsular avulsion. These may also occur at the navicular bone. (B) Extensor digitorum brevis avulsion. Oblique view of the ankle shows thin calcification (arrow) adjacent to the anterolateral calcaneus consistent with an avulsion fracture from the origin of the extensor digitorum brevis tendon. (C) Fifth metatarsal base fracture. AP view of the fifth metatarsal base in a skeletally immature patient shows a longitudinally directed, rounded ossification center (arrow) as well as a transversely directed avulsion-type fracture (arrowheads). Avulsion-type fractures in this location typically extend to the tarsometatarsal articular surface, whereas Jones-type fractures are more distal, occurring at the proximal shaft. (D) Lateral talar process fracture. A fracture of the lateral talar process (arrow), also called a "snowboarder's fracture," is seen on this AP view of the ankle. These fractures are commonly missed and can be a source of chronic pain after a severe ankle sprain. (E) Anterior process fracture of the calcaneus. Lateral view of the ankle shows discontinuity of the anterior calcaneal process (arrow). Like the snowboarder's fracture, this injury is often missed on initial evaluation, resulting in chronic pain.

Figure 6 Talar neck fracture. Lateral view of the ankle shows a displaced fracture of the talar neck (arrow). This injury may be associated with dislocation of the ankle, subtalar, or talonavicular joint, further increasing risk of development of avascular necrosis.

Extensor Digitorum Brevis Avulsion/Dorsal Capsular Avulsion

Capsular avulsions may occur at the talonavicular joint, with small fractures off the superior aspect of the navicular bone or talar head (Fig. 5A). A curvilinear calcification adjacent to the anterolateral calcaneus is classic for avulsion of the extensor digitorum brevis tendon[4] (Fig. 5B).

Fifth Metatarsal Base Fracture and Jones Fracture

The base of the fifth metatarsal may avulse due to traction from the peroneus brevis insertion. This is also known as "avulsion-type" fracture, to differentiate it from the Jones fracture. Both types are transversely oriented. The avulsion-type fracture is more proximal, extending into the fifth tarsometatarsal joint (Fig. 5C). Jones fractures are distal to the joint, generally about 1.5 to 2 cm from the tip, and have a worse prognosis[5]; this injury is often complicated by delayed union and nonunion, probably secondary to poor vascularity, and as such, a low threshold exists for surgical fixation.[6] In children, the normal developmental apophysis at the fifth metatarsal base is longitudinally orientated and does not enter the cuboid-metatarsal joint; this should be differentiated from transversely oriented fractures. One pitfall is that occasionally this apophysis may be bipartite.

Lateral Talar Process Fracture

Termed the "snowboarder's fracture," fractures of the lateral process of the talus were previously a rare injury; however, they are now becoming increasingly more common with the rise in popularity of this sport.[7] The mechanism of injury involves ankle dorsiflexion, generally thought to be combined with hindfoot inversion[8]; however, recent biomechanical analysis proposes that the injury occurs with combined dorsiflexion and eversion.[9,10] These fractures are often missed on initial radiographic evaluation[11] because the lateral process, seen best on the lateral view adjacent to the sinus tarsi, is often overlooked (Fig. 5D). Patients therefore present weeks or months after a severe sprain with chronic lateral pain that has not responded to conservative therapy. The fracture is intraarticular, and if unrecognized, nonunion or malunion may occur, with long-term disability from premature subtalar osteoarthritis. Thus, a high index of suspicion is paramount.

Fracture of the Anterior Calcaneal Process

Fracture of the anterior process of the calcaneus is best seen on the lateral view of the ankle (Fig. 5E). It is due to avulsion of the bifurcate ligament, which attaches the calcaneus with the cuboid and tarsal navicular. Similar to the fractures listed above, this finding is commonly overlooked and can explain persistent pain after ankle sprain.

Talar Neck Fracture

Fractures of the talar neck (Fig. 6) are usually oriented in the coronal plane and are typically secondary to axial loading. When non-displaced, these are designated type I. With increasing injury severity, the fracture posteriorly subluxes or even dislocates, secondary to disruption of the subtalar joint (type II), or both subtalar and tibiotalar joint (type III). Displacement results in disruption of the fragile vascular supply of the talus and commonly results in delayed union, nonunion, and avascular necrosis, the latter occurring in up to 90% of the more severe injuries.[12] The presence of disuse osteopenia results in a subchondral lucency paralleling the talar dome (AP view) in the post fracture assessment radiographs. The presence of this finding (Hawkin's sign) (Fig. 18B) is consistent with the absence of avascular necrosis, since disuse osteopenia implies a degree of vascularization. Conversely, the absence of this sign 3 or 4 weeks after the fracture is associated with a poor outcome, suggesting impending avascular necrosis.

Calcaneal Fracture

Calcaneal fractures can be divided into intraarticular and extraarticular types. Extraarticular fractures consist mainly of avulsions (from the extensor digitorum brevis origin off the anterolateral calcaneus or Achilles tendon avulsion off the posterior tubercle) and anterior process fractures. Achilles avulsions (Fig. 7A) are seen most commonly in diabetics[13]; the others are typically seen in association with ankle sprains.

Of the intraarticular fractures, axial load is the most common mechanism, resulting in an oblique vertical fracture separating the calcaneus into a posterior tubercle fragment

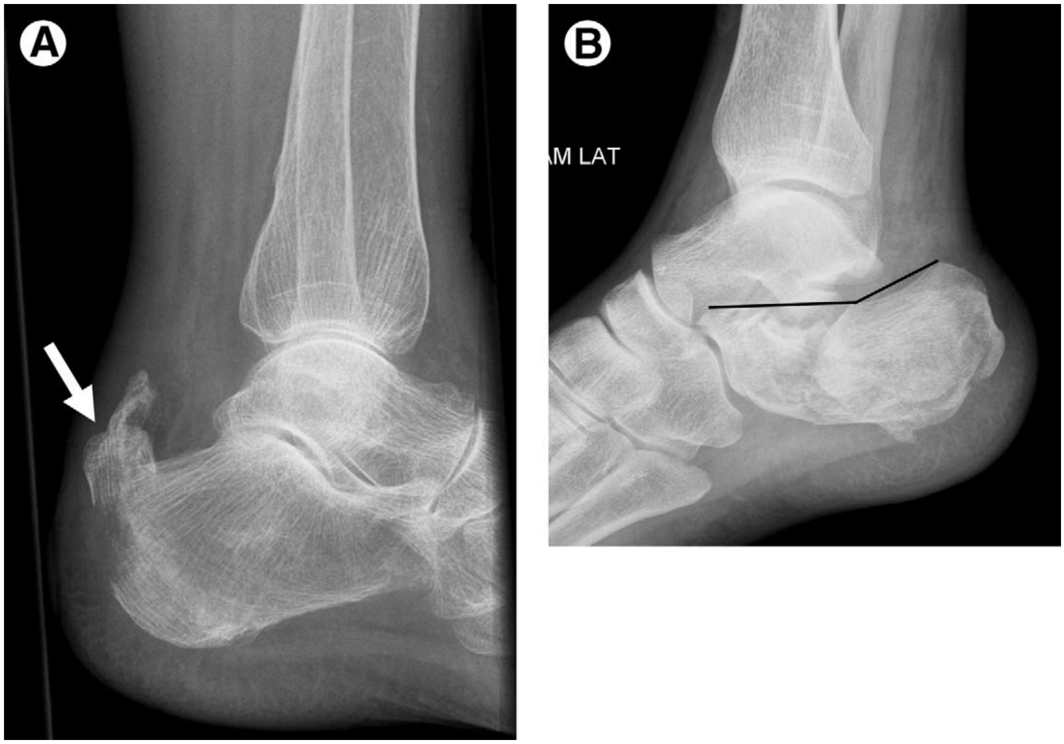


Figure 7 Calcaneal fracture. (A) Achilles avulsion. Along with anterior process fracture depicted in Fig. 5E and extensor digitorum brevis avulsion fracture shown in Fig. 5B, Achilles tendon avulsion (arrow) is classified as an "extraarticular" calcaneal fracture. This fracture is more common in diabetic patients and patients with renal osteodystrophy. (B) Joint depression-type fracture. Resulting from axial load injury, the "joint depression type" is the most common of the "intraarticular" calcaneal fractures. The talus is driven into the calcaneus, displacing the subtalar articular surface into the calcaneal body, flattening Boehler's angle (lines), and typically creating an anteromedial sustentaculum fragment and a posterior tubercle fragment, with varying degrees of comminution and medial-to-lateral widening. The "tongue-type fracture" is described when a curvilinear fragment extending to the posterosuperior calcaneus is rotated downward.

and a sustentacular fragment. A secondary fracture line extends from the angle of Gissane posteriorly, extending to the posterior margin of the subtalar joint (joint depression type, Fig. 7B) or transversely through the tubercle (tongue type). Most are complex, often with marked comminution and displacement. Often the posterior facet articular surface is driven into the body of the calcaneus (Fig. 7B), with flattening of Boehler's angle (normally 20 to 40°). The axial load causes medial-to-lateral widening of the calcaneal body, with lateral wall comminution. The sustentacular fragment is critical for stabilization; if large, it is usually deemed the stable fragment onto which the remaining fragments are fixated. Five to ten percent of intraarticular calcaneal fractures are bilateral and there is also a 10% association with concomitant fractures of the thoracolumbar spine. Long-term complications of comminuted calcaneal fracture include subtalar incongruity and premature osteoarthritis, tendon and nerve entrapment, stenosing tenosynovitis or peroneal subluxation, and malunion resulting in heel deformity.

Lisfranc Fracture-Dislocation

Acute Lisfranc joint disruption is relatively rare but is extremely important to detect early. Injury occurs from twisting at the midfoot, classically resulting from a fall off of a horse or bicycle with the forefoot held in a stirrup. However, it may also occur in the athletic setting when a player steps on an opponent's foot. Intertarsal ligaments support the cuneiforms and cuboid; intermetatarsal ligaments are present attaching the bases of the second through fifth metatarsals. Strong plantar tarsometatarsal ligaments as well as configuration of the bones described above help support the joint. However, there is no intermetatarsal ligament between the first and second metatarsal bases. The Lisfranc ligament accounts for this deficiency, extending obliquely from the medial (first) cuneiform to the second metatarsal base. It is composed of two fascicles, dorsal and plantar, with the latter being stronger. With injury, the Lisfranc ligament may tear or avulse, with a tiny fragment of bone seen in the intervening soft tissues (Fig. 2C). On radiographs, integrity of the Lisfranc ligament can be implied by evaluating the precise longitudinal alignment of the medial aspect of the second metatarsal base with the medial aspect of the second cuneiform; the lateral aspect of the base of the first metatarsal should also align with the lateral border of the first cuneiform. Disruption of this ligament results in subluxation/dislocation of the second to fifth metatarsal bases of the forefoot, usually in a dorsolateral direction. This commonly occurs with a fracture of the second metatarsal base, recessed relative to the other metatarsals. Lisfranc injuries are classified by virtue of the pattern of first metatarsal dislocation with respect to the remaining metatarsal bases: laterally (homolateral pattern) or medially (divergent pattern). Weight-bearing views, although useful for evaluation of alignment, may not be possible due to severe pain. Surgical reduction and fixation is aimed at restoring anatomical alignment and generally requires fusion of the first and second tarsometatarsal joints. If the injury is missed or if treatment is delayed, serious sequelae can result including deformity, chronic pain, and premature osteoarthritis. A normal variant ossicle, the os intermetatarseum, is positioned dorsally between the first and second metatarsal bases and should not be confused for a Lisfranc fracture.

Stress Fracture

Stress fractures can be divided into fatigue fractures (normal bone undergoing abnormal stress, Fig. 8A) and insufficiency fractures (abnormal bone, such as osteoporotic bone, undergoing normal stress; Fig. 8B). Both are related to repetitive injury that is too low to cause an acute fracture, but that exceeds the elastic limit of load-bearing trabeculae. Radiographs are initially normal; healing response causes stress fractures to be visible after a variable delay. The appearance depends on the bone involved. Tubular bones such as the metatarsals develop thick periosteal reaction, which may mimic a healing acute fracture. Tarsal bones lack a defined periosteum, so periostitis is not a prominent feature. Microcallus forms on the fractured trabeculae, forming an ill-defined sclerotic line along the line of force on weight-bearing, generally perpendicular to the trabecular lines. In the calcaneus, multiple fracture lines may develop. The calcaneus and second or third metatarsal neck are the most common sites. A "march" fracture refers to stress fracture of the metatarsal neck, especially common in military recruits. However, the distal tibial metaphysis, talar neck, navicular,[14,15,16] and cuboid may also occur. The fibula is variably weight-bearing and may rarely be involved. If not treated, the stress injury can progress across the bone and create a displaced fracture.

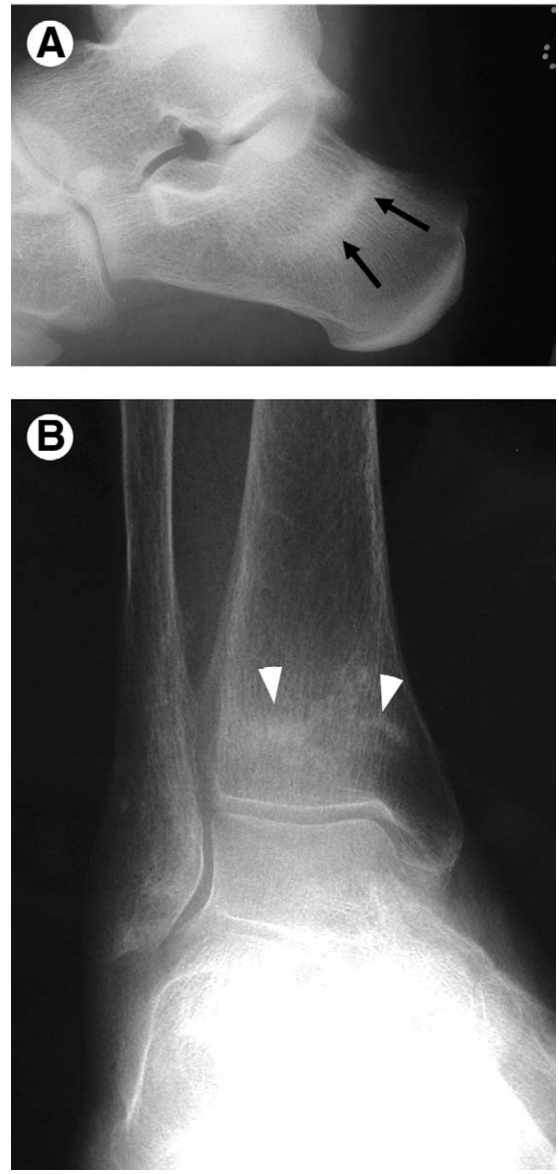
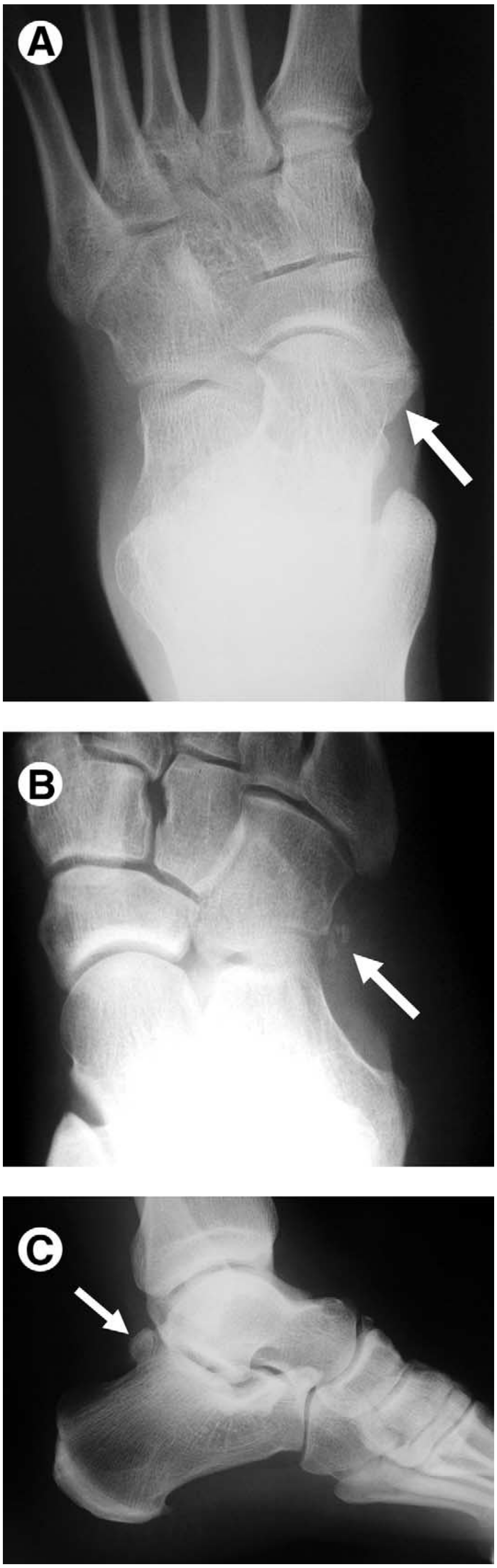


Figure 8 Stress fracture. (A) Calcaneal fatigue fracture. Fatigue fractures are overuse injuries occurring in normal bone. The most common locations in the ankle and foot are the calcaneus (arrows) and the distal second metatarsal shaft. The fracture line is sclerotic, reflecting microcallus forming along the lines of stress perpendicular to the main trabecular orientation. (B) Tibial insufficiency fracture. Insufficiency fractures occur in abnormal (ie, osteoporotic) bone undergoing normal stresses. AP oblique (mortise view) view of the ankle shows demineralized bones with a horizontally oriented dense line (arrowheads) across the distal tibial epimetaphysis, representing an insufficiency fracture.

Normal Variants and Their Implications

Accessory Navicular

The accessory navicular is also known as the os tibiale externum. Three subtypes of the accessory navicular have been described. Type I is a small, round ossicle or sesamoid of the distal posterior tibial tendon. The tendon passes around the ossicle, and this type is not thought to cause pathology. Type II accessory navicular is a larger triangular ossicle with a fibrocartilaginous synchondrosis on the navicular body (Fig. 9A). The posterior tibialis tendon inserts on the os, and chronic traction forces can lead to stress-related changes or even pseudarthosis at the junction. Often occult radiographically, this process may be seen in later stages as sclerosis, separation, and/or cystic change at the junction, often with soft-tissue swelling. Type III or *cornuate navicular* is a completely incorporated ossicle of similar morphology to the type II. The presence of a type II or III accessory navicular predisposes the posterior tibialis tendon to injury and dysfunction, possibly due to abnormal course and altered mechanics of the posterior tibialis. In addition, these types create a bump at the medial foot that is susceptible to friction and direct trauma.



Os Peroneum and Painful Os Peroneum Syndrome

The os peroneum is a common finding lateral to the cuboid and represents an ossicle attached to the sheath of the peroneus longus tendon just proximal to the point at which the tendon courses under the cuboid. If the os peroneum is displaced proximal to the calcaneocuboid joint, the peroneus longus tendon is likely torn distally. However, this finding is quite rare. More common is an entity known as "painful os peroneum syndrome," also called POPS. Clinically there is tenderness over the cuboid; on radiographs the os peroneum is often sclerotic and fragmented (Fig. 9B). Underlying pathology includes distal peroneus longus tendinosis, tenosynovitis, or tear. Although multipartite os peroneum may occur developmentally, if seen, correlation should be performed with clinical examination, MRI, or ultrasound.[17]

Os Trigonum and Posterior Impingement Syndrome

The os trigonum, as its name implies, is a triangular bone at the posterior margin of the talus (Fig. 9C). Present in up to a quarter of the population, it represents the ununited trigonal process of the talus, onto which the posterior talofibular ligament inserts. Demonstrating rounded margins, it is generally straightforward to differentiate from a fracture of the posterior talus, known as a Shepard fracture. If large, the os trigonum can become pinched between the posterior tibia and the calcaneus. This can result in a pseudarthrosis (the ossicle is normally connected to the talus via fibrous synchondrosis), arthritis at the articulation, as well as posterior recess effusion and synovitis.[18]

Hallux Sesamoids: Anatomy and Pathology

Sesamoid bones of the first metatarsophalangeal joint are intratendinous ossicles of the flexor hallucis brevis tendon,

Figure 9 Normal variants. (A) Accessory navicular. AP view of the foot shows a large, triangular accessory navicular bone (arrow) that articulates with the navicular body across a broad, flat surface. As opposed to a small, round accessory ossicle, in this setting the posterior tibialis tendon inserts on the ossicle itself, resulting in altered stresses at the intervening fibrous synchondrosis. (B) Painful os peroneum syndrome (POPS). The os peroneum lies lateral to the cuboid and is part of the peroneus longus tendon sheath, located just proximal to the point at which the tendon changes course and passes under the cuboid. A sclerotic or fragmented os peroneum (arrow) may be associated with distal peroneal pathology, also known as POPS. (C) Os trigonum syndrome. The os trigonum (arrow) represents developmental separation of the posterior talar process (Steida process); often triangular in shape and occasionally large, this ossicle can become impinged between the tibia and calcaneus on plantarflexion, causing disruption of the intervening synchondrosis. Osteoarthritis and posterior ankle or subtalar synovitis may occur and is known as "posterior impingement syndrome."

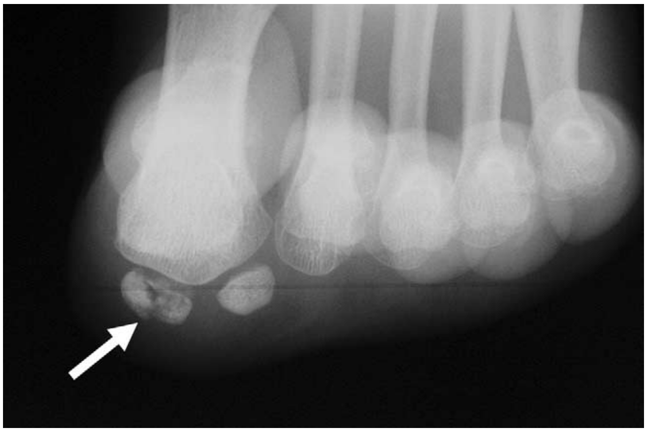


Figure 10 Sesamoid avascular necrosis. Sesamoid view shows sclerosis and fragmentation of the tibial sesamoid (arrow) consistent with avascular necrosis.

with the tibial (medial) sesamoid receiving attachment from the abductor hallucis tendon and the fibular (lateral) from the adductor hallucis. By virtue of their position, tremendous forces are imparted through the sesamoids; therefore, stress injuries and fracture are fairly common.[19] Rarely, in association with "turf-toe," a bipartite sesamoid can be separated due to trauma.[20] Differentiation from a bipartite (or multipartite) sesamoid is important. In the latter condition, well-corticated margins are seen, and the sum of the two components exceeds that of the other sesamoid. Despite this, a painful pseudarthrosis can develop through a bipartite sesamoid, which is not apparent radiographically. The end result of sesamoid fracture and stress is occasionally osteonecrosis, in which the bone appears sclerotic and fragmented (Fig. 10). However, since a healing fracture or stress injury may appear sclerotic, MRI may be needed for differentiation. All of the above conditions are more common in the tibial sesamoid. When conservative measures fail, surgical excision may bring about relief. Therefore, an absent sesamoid usually indicate prior resection, although rarely developmental agenesis occurs. Osteoarthritis is common at the metatarsal-sesamoid joint and is often related to hallux valgus.

Osteochondral Lesions

Osteochondral lesions (also known as osteochondral defects, osteochondritis dissecans, or osteochondral fractures) are most common at the talar dome but can occur at any articular surface. All are considered to be related to trauma, although, whereas acute injury (eg, severe ankle sprain) is implicated most often in lateral talar dome lesions, chronic repetitive injury (eg, sports such as basketball) is typically seen in medial talar dome lesions. Medial lesions are more common.[21] Lateral lesions due to inversion injury occur as the fibula shears across the talar dome; as a result lateral lesions are often shallow or wafer-like and have a propensity to be unstable (Fig. 11). Medial lesions are often deep and cup-like.[22] In the long term, the subchondral bone or fragment may become necrotic, unstable, and break free to form a loose body. Radiographic evidence of cystic change beneath the fragment or displacement is indicative of instability. A careful search should be made for a loose fragment if a characteristic donor site is detected. Similarly, if there is evidence of acute or prior ankle injury, the talar dome should be scrutinized for an osteochondral lesion. AP and mortise views are most helpful for detection. If the sclerosis is more diffuse or centralized, frank avascular necrosis should be considered. If changes are seen on both sides of the joint, the subchondral changes may merely represent osteoarthritis.

Arthritis

Degenerative

Degenerative arthropathy, or osteoarthritis, commonly affects the ankle. Classic signs include joint space narrowing, marginal osteophytes, intraarticular body formation, subchondral cysts, and subchondral sclerosis. Trauma is the most common predisposing factor, including injuries such as lateral ligament tear with resultant instability and/or osteochondral injury, as well as intraarticular fracture. Osteoarthritis is also quite common at the midfoot, typically resulting in dorsal spurring at multiple articulations (also called "dorsal proliferative change"). This process is seen in the elderly

Figure 11 Osteochondral lesion of the talus. AP view of the ankle demonstrates a slightly separated wafer-like osteochondral lesion (arrow) at the lateral talar dome.

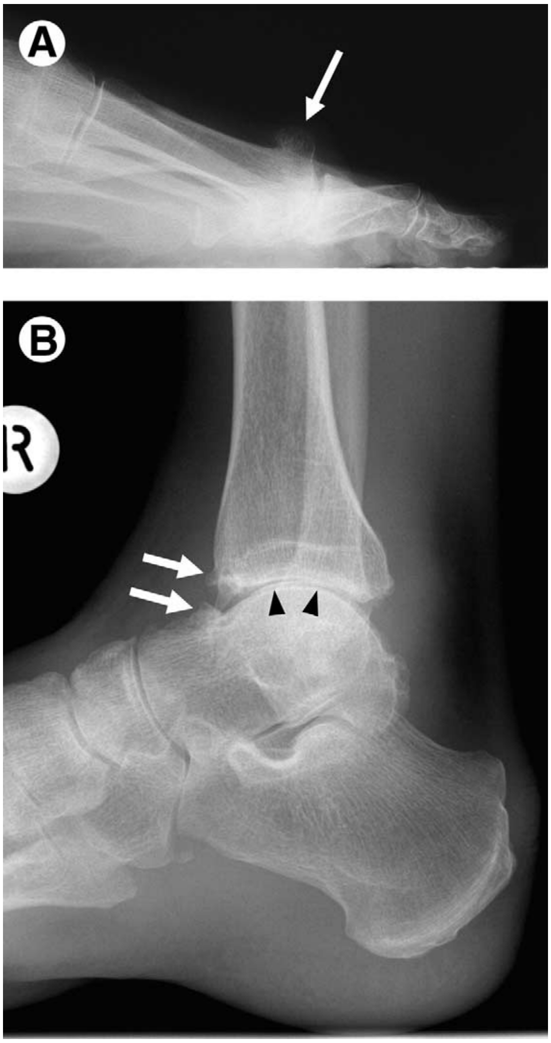


Figure 12 Osteoarthritis. (A) Osteoarthritis of the first metatarsophalangeal joint is common; a prominent dorsal osteophyte may form (arrow) called a "hallux rigidus spur." Like impingement syndromes at the ankle, this condition is associated with pain and limited range of motion at the joint. (B) Ankle joint osteoarthritis with anterior impingement. Lateral view of the ankle shows narrowing of the ankle joint (arrowheads) and subchondral sclerosis representing osteoarthritis. Anterior spurs (arrows) can cause pain and limited dorsiflexion, called "anterior impingement."

but may be accelerated by foot deformity from tendinopathy, neuropathic disease, as well as Lisfranc injury. Osteoarthritis in the toes is also very common in older individuals and is particularly common in the setting of underlying deformity, especially at the first metatarsophalangeal joint in hallux valgus. Occasionally large spurs extend dorsally from the first metatarsal head, resulting in pain on dorsiflexion and limited range of motion, a condition known as "hallux rigidus" (Fig. 12A).

Osteoarthritis can also be secondary to cartilage loss from prior inflammatory arthropathy such as rheumatoid arthritis and gout. In this case, findings of the underlying arthropathy (eg, erosions, soft-tissue swelling) may coexist with typical changes of osteoarthritis, which can lead to confusion. When the inflammation enters remission, radiographs may show only severe osteoarthritis in an unusual distribution typical of an inflammatory arthropathy. Distribution, history, or detection of sclerotic erosions may lead to the correct diagnosis. Hemophilic arthropathy has a predilection for weight-bearing joints with the ankle being a common site. In this instance, prominent geode formation and a hyperdense effusion should alert the examiner to the diagnosis. During development, hemorrhage within the distal tibial growth plate can result in an asymmetric growth disturbance specific for hemophilia, often called "tibial tilt" (or incorrectly as "talar tilt").

Anterior Impingement

Painful impingement at the ankle joint on dorsiflexion can be caused by osteophytes at the anterior joint margin (Fig. 12B). These spurs may be related to osteoarthritis but can also be seen in athletes, especially those involved in kicking sports. The spurs are often anteromedial, with "kissing" projections off the tibia and superior talar neck. Joint effusion can develop, with synovitis and intraarticular bodies in the anterior recess.

Inflammatory Arthropathy

The appearance of *rheumatoid arthritis* in the foot mirrors the changes seen in the hand. The findings are those typical for a symmetric inflammatory chronic synovitis with pannus formation. The inflammatory nature of the pannus results in effusion and periarticular soft-tissue swelling with bone erosions of the portion of intracapsular bone not covered by hyaline cartilage, the so-called "bare area"; however, in small joints these marginal erosions may coalesce and create a destructive appearance. In the foot, rheumatoid arthritis has a predilection for the metatarsophalangeal joints, especially the fifth (Fig. 13A). Periarticular osteopenia is variably present. Although the intertarsal, subtalar, and ankle joints may be involved, this is less common than corresponding carpal involvement in the wrist. However, when these joints are involved, uniform joint narrowing and erosions may be seen. Involvement at the ankle can create a characteristic erosion of the synovial recess at the distal tibiofibular joint. Joint destruction and capsular distension can result in deformities including subluxation/dislocation. Chronic inflammatory tenosynovitis can result in tendon tear and dysfunction, causing additional deformity; posterior tibial tendon dysfunction is particularly common.

Psoriatic arthritis is a seronegative arthropathy and enthesopathy, where erosions and bone proliferation occurs. In the foot, this typically affects the metatarsophalangeal and interphalangeal joints (Fig. 13B). Interphalangeal erosions may result in the pathognomonic "pencil-in-cup" appearance. Acro-osteolysis can occur along with nail involvement. Proliferative bone formation manifests as periostitis and in areas of bone erosion fluffy bone production occurs. Occasionally, if severe, erosions may result in ankylosis or joint destruction (arthritis mutilans). Enthesial involvement resulting in erosions or "fuzzy spurs" may occur at the plantar fascia or other tendon, ligament, or fascial attachment sites. Bursitis may also occur with focal soft-tissue swelling.

Figure 13 Inflammatory arthritis. (A) Rheumatoid arthritis. AP view of the forefoot of a patient with rheumatoid arthritis shows marginal erosions at the metatarsophalangeal joints (arrowheads), particularly the fifth, which is the most common site of involvement by rheumatoid arthritis in the foot. (B) Psoriatic arthritis. AP view of the forefoot demonstrates "whittling" or "penciling" of the second through fifth phalangeal bones. In addition there is fusion of the first interphalangeal joint with adjacent fluffy bone proliferation ("whiskering," arrow), seen in the setting of psoriatic arthritis. (C) Gout. AP view of the forefoot shows severe erosions at the metatarsophalangeal joints and at the Lisfranc joint (short arrow). Note the periarticular location of some erosions (arrowheads), often seen in the setting of tophaceous gout. Although tophi (long arrow) rarely calcify, they are typically high in radiographic density.

Reiter Disease, or reactive arthritis, like psoriatic arthritis, is a seronegative arthropathy and enthesopathy. It appears radiographically indistinguishable from psoriatic arthritis, but has a strong male predominance. There is an association with urethritis and conjunctivitis, with Chlamydia infection.

Gout is an acute, relapsing inflammatory arthropathy related to intraarticular and soft-tissue deposition of monosodium urate crystals. The feet are a common site of involvement, as the lower temperature facilitates crystal precipitation. Acute gout has a nonspecific appearance and may simulate septic arthritis clinically and radiographically. With time, the classical features affecting the metatarsophalangeal joint of the foot, particularly the great toe, occur radiographically. Due to successful modern medical treatment, gout rarely reaches the chronic tophaceous phase once described. When tophi occur, they may be present within the soft tissues, bone, and even within joints themselves. Tophi rarely calcify but have classically increased density compared with adjacent soft tissues (Fig. 13C). Since tophi are not symmetric around the joint, they create a "lumpy-bumpy" pattern of soft-tissue swelling that is fairly characteristic of gout; conversely, arthropathies resulting in synovial proliferation cause symmetric ("fusiform") swelling at joints. Extraarticular tophi can erode into the bone external to the joint, creating the classic "rat bite" erosion with overhanging edges that, again, involves the bone asymmetrically. However, in the US, effects of intraarticular crystal deposition are far more commonly observed radiographically compared with manifestations of tophaceous gout. Recurrent intraarticular inflammation can cause marginal and even central erosions; in the late stages, chronic, sclerotic erosions may be seen in a background of osteoarthritis. When erosions are absent, osteoarthritis is often the only finding. In this case, symptoms and osteoarthritis in the classic distribution (first interphalangeal joint, first metatarsophalangeal joint, occasionally the Lisfranc joint) may suggest the diagnosis. Erosions may occur at the plantar fascia origin, and bursal inflammation may result in a retrocalcaneal bursitis, which if severe, can erode into the posterosuperior calcaneal margin. Bursitis commonly occurs medial to the first metatarsal head; resultant erosions in this location are often confused for cystic changes occurring at bunion deformities. These bursal findings may also be seen in other inflammatory arthropathies.

Pigmented Villonodular Synovitis (PVNS) and Synovial Osteochondromatosis

These disorders are uncommon, but should be considered in cases of unexplained monoarticular disease in young adults when other arthropathies fail to fit the clinical picture. PVNS is caused by benign proliferation of hemosiderin laden synovium. The disorder typically affects the knee or hip, although the ankle is the third most common site. Characteristic features include the preservation of bone mineral density and joint space (except until late in disease), and synovial swelling, which may be dense. The process may be diffuse or focal. Erosions occur in small joints mimicking rheumatoid arthritis. The synovium in PVNS does not calcify. Calcified foci exclude the diagnosis and should raise the possibility of synovial osteochondromatosis, another rare monarticular arthropathy caused by chondroid metaplasia of the synovium. Like PVNS, focal and diffuse forms exist. Chondroid tissue on the synovium often calcifies, forming numerous bodies of similar size, which, in addition to disproportionate lack of joint narrowing and osteophytes, helps differentiate this process from typical osteoarthritis.

Septic Arthritis/Osteomyelitis

Septic arthritis of the foot and ankle, like any other region, may occur secondary to penetrating trauma/direct implantation, postoperatively, due to contiguous spread, or hematogenous spread. The imaging features consist of a joint effusion, with loss of the sharp cortical margins of the subarticular bone. Joint space loss is rapid in acute septic arthritis, and marginal erosions may develop (Fig. 14), mimicking an inflammatory arthropathy, which is why it is essential for each case to be viewed in the context of the clinical setting; a monarticular arthropathy must be considered suspicious for infection. The underlying infective arthropathy may be a consequence of, or may result in, adjacent osteomyelitis, and thus features of osseous involvement should be sought.

Figure 14 Septic arthritis and osteomyelitis. AP view of the great toe of a diabetic patient shows marked soft-tissue swelling around the first metatarsophalangeal joint, which is narrowed with marginal erosions (arrows) and bone destruction consistent with septic arthritis and osteomyelitis.

Osteomyelitis of the foot and ankle is usually seen in susceptible populations, particularly diabetic or paralyzed patients. In these patients, contiguous spread is by far the most common mode of infection, arising via skin ulceration. Therefore, when reviewing radiographs in patients with suspected infection, careful attention should be paid to the soft-tissue findings. Ulcers are seen as a focal distortion of the skin margin on a tangential view and occasionally as a focal lucency when imaged en face. In advanced cases, soft-tissue air is often seen due to communication with an ulcer; it rarely implies gas gangrene. Cellulitis is seen as soft-tissue swelling, although diabetic patients often have a baseline appearance of diffuse soft-tissue swelling due to vascular and neurologic disease. In the early stages of osteomyelitis, bone rarefaction occurs, followed by an aggressive permeative appearance, often with associated thick periosteal reaction.

Brodie Abscess

Brodie abscesses are chronic hematogenous bone infections that are classically solitary, metaphyseal in location, involving the distal tibia most commonly. These infections classically occur in adolescents with open physeal plates. The infected nidus creates an ovoid lytic lesion often with thick, sclerotic margins. Thick periostitis may be seen but not in all cases. If extension to the physeal plate is seen (resulting in a "dripping" or "lollipop" appearance), this is considered pathognomonic. The organism cultured is typically *Staphylococcus aureus*. Multifocal infections can occur in the setting of

Figure 15 Neuropathic osteoarthropathy. Lateral view of the ankle demonstrates radiographic findings of neuropathic osteoarthropathy: Dislocation, disorganization, debris, and preservation of bone density.

chronic recurrent multifocal osteomyelitis (CRMO), which may be of viral origin or may be related to an immunocompromised state.

Neuropathic Osteoarthropathy

Neuropathic osteoarthropathy is an arthritic process that is often aggressive, resulting from repetitive micro- and macrotrauma that heals ineffectively due to ischemia and reduced nociception. Resultant ligamentous insufficiency and tear as well as articular distortion lead to subluxation, dislocation, and other malalignment. Deformity causes additional stress facilitating additional injury. Although the disease may be seen in various neurological conditions involving the foot/ankle such as leprosy, in the US it is overwhelmingly most common in diabetics with peripheral neuropathy. In this population, the Lisfranc joint and intertarsal joints are most commonly involved, followed by the Chopart joint, subtalar and tibiotalar joint, and the metatarsophalangeal joints. Since the etiology is based on injury, deformity, and stress, often multiple joints in a localized region are affected. Radiographically in the early stage little is seen apart from diffuse soft-tissue swelling and occasionally mild offset of a joint. The disease may progress rapidly, with erosions and even frank joint destruction. This finding, along with soft-tissue swelling, may be indistinguishable radiographically and clinically from osteomyelitis, and MRI or scintigraphy may be needed. Often in the late stage there is excessive bone production (sclerosis and spurring), and subchondral cystic change which in addition to deformity leads to the classic appearance of chronic neuropathic osteoarthropathy. Articular surfaces degenerate over time and may fragment, becoming distorted, incongruent, and generally disorganized, with debris and body formation (Fig. 15). In fact, neuropathic osteoarthropathy has been characterized radiographically as dislocation, debris, disorganization, deformity, and increased density, the description itself being a conveniently alliterative memory tool. In diabetics, this deformity results in alteration of weight-bearing stresses. Midfoot involvement in particular leads to collapse of the arch and superior subluxation of the metatarsal bases; the cuboid is then exposed to weight-bearing stresses, and callus, ulceration, and infection may ensue. Deformity of the ankle and foot can also cause shoes to fit poorly, which in the setting of neuropathy can lead to other sites of ulceration.

Radiographs of diabetic patients with vasculopathy often demonstrate linear tram-track vascular calcification. Soft-tissue calcification is also seen in leprosy, a relatively common cause of neuropathic osteoarthropathy worldwide; in this disease calcification of the interdigital nerves may be seen.

Tendon Pathology

Posterior Tibialis Tendon

The posterior tibialis tendon courses posterior to the medial malleolus, extending obliquely to insert predominantly on the posteromedial navicular bone. The posterior tibialis functions to plantarflex and invert the foot, but also plays a passive stabilization role, by supporting the medial arch and hindfoot alignment. In the setting of atrophic or hypertrophic tendinosis, the PTT may become dysfunctional, resulting in pain and deformity. Posterior tibialis tendon pathology undergoes four stages: Stage one is tenosynovitis without dysfunction or deformity. Stage two includes a flexible deformity, seen only on weight-bearing images. Stage three is a fixed foot deformity. The fourth stage is osteoarthritis related to the foot deformity and instability. The deformity that results from posterior tibialis tendon dysfunction results in a constellation of findings that include pes planus, hindfoot valgus, and collapse of the medial longitudinal arch. There is also overpronation of the foot and forefoot abduction (Fig. 2B). Predisposition to posterior tibialis tendon pathology may be seen in the setting of a large accessory navicular ossicle or cornuate navicular bone.

Achilles Tendon

The Achilles tendon is formed by the confluence of the gastrocnemius and soleus tendon. Tendinopathy manifests as soft-tissue thickening and is divided into insertional and noninsertional groups. Noninsertional tendinopathy is usually in the form of tendinosis, which on radiographs characteristically occurs 2 to 6 cm superior to the calcaneal insertion, a zone of relative ischemia. Weakening of the tendon predisposes it to mechanical failure and ultimately complete acute disruption, again, at the same site. Inflammatory change associated with peritendinitis, as well as retrocalcaneal bursitis, may result in obscuration of the pre-Achilles (Kager's) fat pad. Retrocalcaneal bursitis may occur as a repetitive micro-traumatic/friction-type phenomenon; however systemic inflammatory arthropathies, such as rheumatoid and seronegative arthritis as well as gout, may affect the bursa, as well as result in associated calcaneal erosion. Shoes that are ill fitting may result in the characteristic "pump-

Figure 16 Haglund syndrome. Lateral radiograph shows an upturned posterior calcaneal tubercle (arrowhead) with soft-tissue swelling (short arrow) corresponding to the retro-Achilles bursa. Also note calcification of the distal Achilles tendon (long arrow), often seen after healing of tendon tear.

bump" deformity. This constellation of findings consists of thickening of the distal Achilles tendon as well as superficial tendo Achilles and retrocalcaneal bursitis. Haglund's deformity, a prominent posterosuperior calcaneal (bursal) projection, diagnosed by assessing parallel pitch lines, predisposes patients to retrocalcaneal bursitis and Achilles tendinopathy, the so-called Haglund painful heel syndrome[23] (Fig. 16). Insertional tendinosis maybe secondary to an overuse phenomenon; however, enthesopathy related to an inflammatory arthropathy should be borne in mind. Both may be associated with calcific foci within the tendon.

Plantar Fasciitis

Plantar fasciitis is a painful condition caused by repetitive injury to the proximal plantar fascia, at or near its origin from the calcaneus. Individuals with pes planus and overpronation are predisposed. Although spur formation at the inferior calcaneus is often implicated in this process, it actually has little association with pain; the spur is merely an enthesophyte, and like enthesophytes elsewhere in the body, they are often seen incidentally. The pathologic lesion is in the adjacent soft tissues, and although plantar fascial thickening may be suggested on the lateral radiograph, this finding is not necessarily related to acute, symptomatic fasciitis.

Morton Neuroma

Morton neuroma is actually perineural fibrosis[24] resulting from repetitive injury to the plantar interdigital nerve in the confined space as the nerve passes the metatarsal heads. Usually this occurs in the second or third intermetatarsal space. Generally a clinical or cross-sectional imaging diagnosis,[25] Morton neuroma may be suspected radiographically if there is a disproportionate separation of metatarsal heads on the weight-bearing AP view of the foot (Sullivan's sign).

Freiberg's Infraction

This entity is characterized by flattening of the second or rarely the third metatarsal head. Squaring of the first metatarsal head is normal; a minimally flattened appearance can be normal at the second through fifth; however, when prominent, disproportionate, or sclerotic, Freiberg's can be suggested (Fig. 17). Although described as avascular necrosis, its etiology is more likely developmental and traumatic. Predilection for the second metatarsal head is thought to be related to the fact that the longer second metatarsal is susceptible to chronic repetitive injury. Over time an osteochondral lesion results, typically at the anterosuperior aspect of the second metatarsal head. The lesion may heal with a flattened appearance or undergo necrosis, with further collapse. The deformity may cause secondary osteoarthritis. A similar appearance to Freiberg's infraction may be seen as a complication of diabetic-related neuropathy.[26]

Osteonecrosis

Osteonecrosis (also called bone infarction or avascular necrosis) may affect any bone in the foot, but most commonly involves the talus due to its relatively tenuous vascular supply. Metabolic conditions such as sickle cell disease and lu-

Figure 17 Freiberg's infraction. Flattening of the second metatarsal head (arrow) is compatible with Freiberg's infraction. This condition is most common in individuals with a long second metatarsal, resulting in increased stresses across the articular surface. Note osteophytes (arrowheads) representing secondary osteoarthritis.

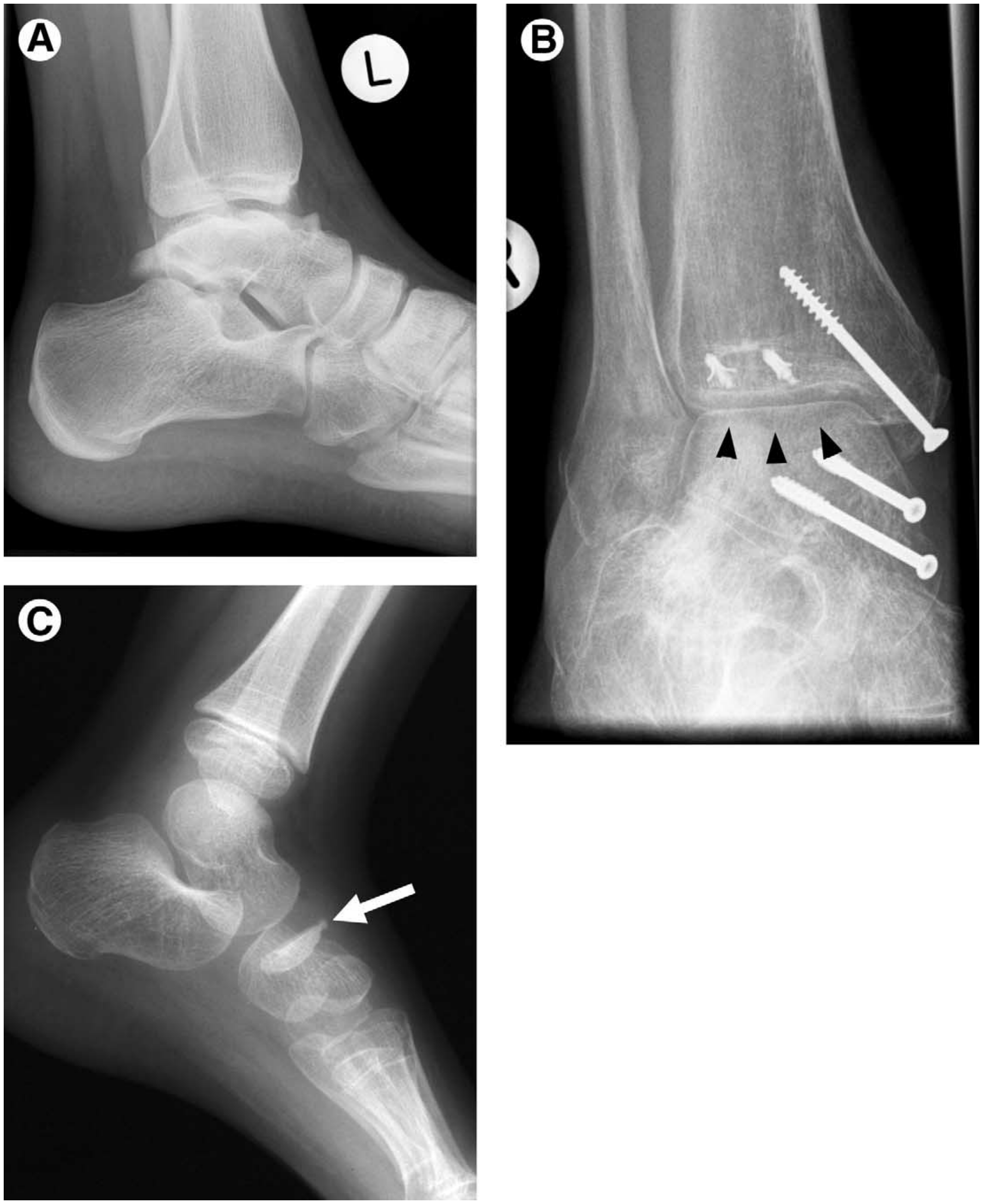


Figure 18 Osteonecrosis, Hawkin's sign, and "osteochondrosis." (A) AVN with collapse. Lateral view of the ankle demonstrates sclerosis of the talus with collapse of the articular surface representing osteonecrosis. (B) Hawkin's sign. AP view of the ankle of a different patient after fixation shows lucency in the subchondral bone of the talar dome (arrowheads). This is a sign that there has been bone resorption and suggests absence of avascular necrosis. (C) "Osteochondrosis." Sclerosis of the navicular bone (arrow) is present in this skeletally immature patient. Originally described as one of the "osteochondroses" (Kohler's disease), it has been recognized that some represent normal variation rather than osteonecrosis.

pus, as well as steroid therapy, may result in osteonecrosis in multiple bones. Severe ischemia due to diabetes can also result in multifocal infarctions. Talar osteonecrosis (Fig. 18A) may be caused by these conditions but is particularly common after talar fracture, especially talar neck fractures associated with displacement.[27] Postoperative osteonecrosis can occur due to inadvertent interruption of blood supply, such as in the first metatarsal head following distal metatarsal osteotomy in hallux valgus surgery.

In the early stages osteonecrosis is not visible radiographically, although it may be suggested by *lack* of bone resorption after immobilization relative to adjacent bones. Subchondral bone resorption in the talar dome is known as "Hawkin's sign" (Fig. 18B), a useful sign that argues against osteonecrosis, since blood flow must be intact to resorb calcium in bone. In the later stages of osteonecrosis sclerosis occurs and is often well-defined, with a sharp angular marginal pattern. Necrosis weakens the bone and collapse may occur, especially in weight-bearing bones such as the talus. After collapse, severe secondary osteoarthritis generally ensues rapidly.

Sclerosis of bone with a fragmented appearance in certain settings, especially in the pediatric population, was previously referred to as "osteochondrosis," a now anachronistic term; different names were applied depending on the bone involved. These findings encompass a number of etiologies with convergent radiographic findings, such as normal developing bone (Sever's disease of the posterior calcaneal apophysis; Kohler's disease of the navicular; Fig. 18C), true osteonecrosis (Mueller–Weiss disease of the lateral navicular bone), as well as traumatic conditions (Freiberg's infraction of the second metatarsal head). Findings should always be correlated with symptoms, however, with comparison to the asymptomatic side if necessary, to differentiate normal variation from true disease.

Tarsal Coalition

Coalition is an abnormal union between two bones. The connection may be osseous (with medullary contiguity), fibrous (with an intervening fibrous synchondrosis), or cartilaginous (with intervening cartilage or an abnormal joint at the junction). The foot is a common location; however, actual incidence is difficult to determine since many coalitions are asymptomatic, and the condition occurs along a spectrum from bones that approximate each other, to frank osseous connections. This leads to differences in reader interpretations as to what cut-off point to call a coalition; this is particularly true at the calcaneonavicular junction.[28] Despite this limitation, it is clear that talocalcaneal (subtalar) and calcaneonavicular coalition account for over 90% of ankle coalitions. Coalitions are confluences of developing cartilage. In childhood, these are typically asymptomatic, since the cartilaginous ossification centers allow some degree of flexibility and motion. Symptoms generally begin around adolescence.[29] As the tarsal bones ossify, the coalition stiffens, and patients present with a painful, stiff ankle. Due to altered mechanics, effects can be seen in other bones, often resulting in talar beak formation (an osseous projection from the superior talar head) and bone proliferation around the coalition itself. When a talar beak is observed, a coalition should be sought. However, dorsal capsular spurs can simulate a talar beak.

Calcaneonavicular coalition (Fig. 19A-B) is seen on the lateral view as an "anteater sign," formed by the prominent anterior process of the calcaneus, the end of which cannot be seen. However, this coalition is best seen on the external oblique view of the foot, which projects the radiograph beam directly through this junction; any connection between the bones is abnormal.[30]

Subtalar coalition (Fig. 19C-D) occurs at the middle facet and is often detected based on the osseous proliferation occurring at the sustentaculum tali. This proliferation causes the sustentaculum to be prominent on the lateral ankle view; the margin of the bone blends with that of the posterior talus and talar dome, creating a complete "C"-shape.[31] Initially, the C-sign was reported as being present in as much as 98% of patients[32]; however, this has not been reproducible since.[33] Furthermore, the specificity of the sign has also been questioned, as it has also been noted in painful flatfoot deformity.[34] The best view for this coalition is the Harris–Beath view (skier's view), which directs the radiograph beam parallel to both the middle and the posterior subtalar facet in the normal situation. In a coalition, the posterior facet will be seen well and the middle facet will not.[35] On the frontal ankle view, occasionally the bone proliferation and abnormal downward-tilted middle facet can be seen at the medial margin of the subtalar joint.

Neoplasia

Tumors affecting the foot and ankle are rare, though most are benign, outweighing malignancies by four to one. Most are benign and involve the soft tissues,[36] consisting of vascular abnormalities, ganglion cysts, the fibromatoses, and lipomas. These lesions are typically not routinely seen on radiographic imaging, with the exception being the demonstration of a phlebolith in the context of a hemangioma.

In the tarsal bones and small bones of the foot, the periosteum is not well developed, and therefore, periostitis or lack thereof is not a reliable sign. Nevertheless, several benign/nonaggressive osseous lesions have characteristic appearances that usually require no differential diagnosis on the basis of their site and morphology. These include cysts and lipomas (Fig. 20A), fibroxanthomas (also called nonossifying fibromas or fibrous cortical defects), enchondromas, and osteochondromas (Fig. 20B). In the foot and ankle region, nonossifying fibromas are most commonly located in the distal tibia and are characteristically metaphyseal in location. Diaphyseal extension and progressive sclerosis occurs with skeletal maturity. These common lesions have a thin, sclerotic border, with a scalloped margin, and are minimally expansile. Enchondromas are most commonly phalangeal in location, in which case, are devoid of the typical chondroid calcifications found in these lesions at other sites. The lesions are asymptomatic and are without a periosteal reaction. The development of such clinical/radiological findings may indicate pathologic fracture or malignant transformation.

Osteochondromas (also called osteochondral exostoses or OCE) are more common around the knee but are occasionally seen in the distal tibia, often extending along the interosseous membrane at the tibiofibular interval. Due to the extrinsic pressure over time, the fibula remodels, forming a thin, C-shaped deformity around the osteochondroma (Fig. 20B). Far more common in this location is ossification of the interosseous membrane due to prior injury, which may be symptomatic and should not be confused for tumor.[37] Cysts and lipomas are common in the body of the calcaneus, just inferior to the angle of Gissane. A calcaneal intraosseous li-

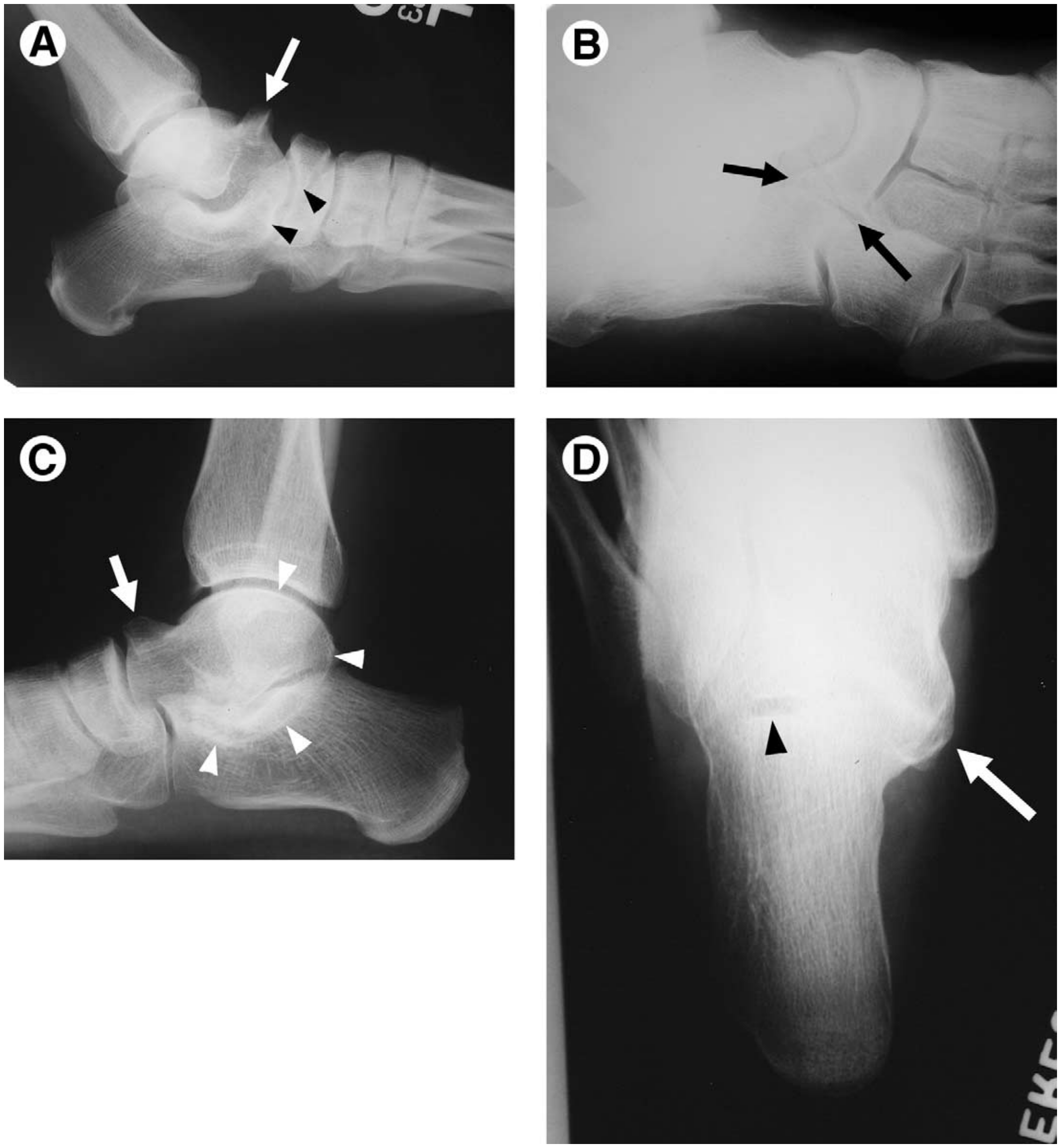


Figure 19 Coalition. (A) Calcaneonavicular coalition. Lateral view of the ankle shows a talar beak (arrow), which is often associated with coalition. Note the "anteater sign," in which the anterior calcaneal process (arrowheads) continues into the navicular bone, caused by a coalition. (B) Calcaneonavicular coalition. Lateral oblique view of the foot of the same patient as (A) optimally depicts the site of calcaneonavicular coalition (arrows). (C) Subtalar coalition. Lateral view of the ankle shows a talar beak (arrow) and a "C sign" (arrowheads) caused by a prominent sustentaculum tali seen in the setting of subtalar coalition. (D) Subtalar coalition. Harris–Beath view of the same patient as (C) shows bone prominence at the sustentaculum tali (arrow) and lack of visualization of the middle facet compared with the posterior facet (arrowhead), which should be in the same plane.

poma is a lucent lesion with well-defined margins and may have centrally placed foci of dystrophic "popcorn-like" calcification (Fig. 20A). A simple (unicameral) bone cyst of the calcaneus can occur at the same location and also possesses thin, sclerotic margins. Since both lipomas and cysts are lucent, CT or MRI can be used to differentiate the lesions if necessary. Rarely these lesions may become symptomatic and require curettage. Small sclerotic lesions with a central lucent nidus in young patients with night pain should raise the possibility of an osteoid osteoma.

Malignant primary soft-tissues lesions have a nonspecific appearance, such as having mass effect, abnormal of soft tissues contours and planes, as well as occasionally an aggressive appearance to the underlying osseous structures. This includes a narrow zone of transition, a lytic/permeative appearance, and an immature periosteal reaction. The most common soft-tissue malignant lesion of the foot is the synovial sarcoma. Plain radiographs, though normal in half the cases, may demonstrate calcification in a third of cases and, less commonly, bone destruction.[38] Ewing's sarcoma is more common than osteosarcoma in the foot, being predominantly diaphyseal in location and having a moth-eaten lytic morphology with an aggressive periosteal reaction. Osteomyelitis and hematological malignancies (leukemia and lymphoma)

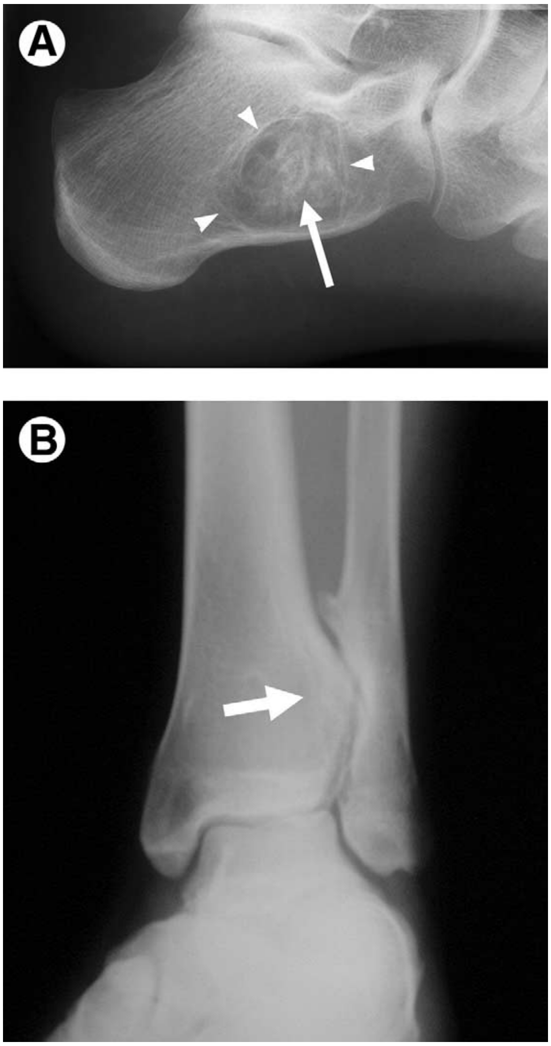


Figure 20 Neoplasm. (A) Lipoma. Lateral view shows a lesion in the calcaneal body with thin, sclerotic margins (arrowheads) consistent with a nonaggressive lesion. This is a characteristic location for cysts and lipomas; internal calcification (arrow) narrows the differential to a lipoma. (B) Osteochondral exostosis (OCE). Ossification may be seen at the tibiofibular syndesmosis after injury; however, this projection (arrow) from the distal tibia laterally demonstrates medullary contiguity with the tibia and represents an osteochondroma. This is a common location at the ankle; due to tight tibiofibular attachments, the fibula remodels over time around the exostosis.

should be considered as differential diagnostic possibilities when a permeative lesion is seen. Metastases and myeloma are uncommon in the foot and ankle, and if present, are usually widely distributed in other, more classic areas of the body containing hematopoietic marrow; therefore, if a lesion cannot be characterized as benign, a work-up should be performed, which can include a skeletal survey, bone scan, and/or MR imaging.

Conclusion

Foot and ankle disorders are common, yet potentially complex, representing a range of conditions, from acute trauma to chronic inflammatory and neoplastic processes. The initial evaluation should always commence with plain radiographic assessment, as radiographs are readily available and have a high diagnostic yield considering the relative low cost. A thorough knowledge of the radiographic features is imperative, as careful interpretation may obviate the need for further investigation. In the absence of this, when a specific diagnosis is not possible, an adequate radiographic assessment still remains vital, as its serves as a guide for the clinician to the next most effective imaging modality.

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