

Ankle Trauma

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This chapter reviews the anatomy of the ankle joint and illustrates the common ankle injuries imaged emergently using radiography and CT, including the following fractures: Weber, pilon, juvenile Tillaux, and triplane.

This chapter accompanies my lecture on ankle trauma presented as part of the Categorical Course Syllabus titled State-of-the-Art Emergency and Trauma Radiology at the 108th annual meeting of the ARRS held in Washington, DC, on April 17, 2008. For a more complete discussion of CT and MRI of the ankle and foot, I suggest you read my chapter in *Computed Tomography and Magnetic Resonance Imaging of the Whole Body* [1], a two-volume set edited by John R. Haaga and colleagues. You can download that chapter, and my other lecture materials on musculoskeletal imaging and about PowerPoint (Microsoft), at my Website, www.schreibman.info.

Anatomy

The ankle joint is the articulation between the dome of the talus and the distal tibia and fibula (Fig. 1A). “Ankle joint” is the preferred name of this joint in the radiology and orthopedic surgery literature, rather than “tibiotalar joint” or “crural joint.” The flat talar dome articulates with the flat surface at the distal end of the tibia known as the plafond (Fig. 1B). “Plafond” is an architectural term, meaning “a ceiling formed by the underside of a floor.” In essence, the plafond is the ceiling of the ankle joint that is formed by the floor of the tibia. The ankle joint is bounded on the sides by the inner articular surfaces of the medial and lateral malleoli. The plafond together with the malleoli form a rectangular opening called the mortise into which the talar dome fits, analogous to a mortise-and-tenon joint in woodworking. The ankle mortise is a remarkably sturdy joint. Like the hip and knee joints, the ankle joint must bear our entire body weight with every step. However, although it is common for primary osteoarthritis to affect the hips and knees of many of us as we age, it is uncommon to be afflicted with primary osteoarthritis of the ankle.

The joint between the distal tibia and fibula is called the syndesmosis. “Syndesmosis” is a Greek term meaning “to bind together,” and in general a syndesmosis joint is held together by thick connective ligaments. Most other joints in the body, including the ankle and subtalar joints, are synovial joints in that they are enclosed by a synovium-lined capsule that creates synovial fluid. The distal fibula, just above the lateral malleolus, fits into a shallow groove in the adjacent tibia, and this relationship is best visualized in the axial plane of a CT scan.

Keywords: ankle joint, CT, juvenile Tillaux fracture, pilon fracture, radiography, triplane fracture, Weber fracture

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Imaging Ankle Trauma in the Emergency Department

All ankle imaging examinations should begin with radiographs; for common twisting injuries, such as the Weber fractures I discuss later in this chapter, rou-

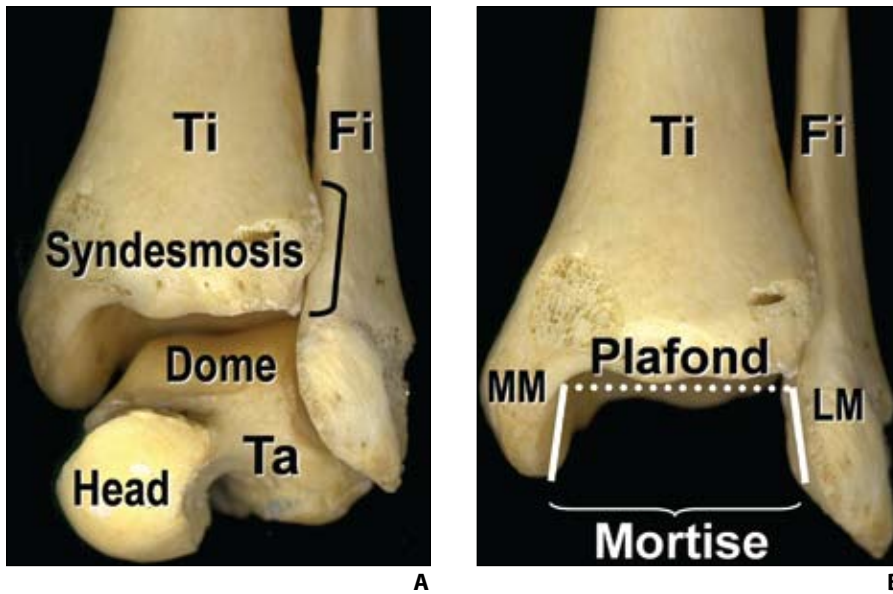


Fig. 1—Gross anatomy of ankle joint. Ti = distal tibia, Fi = fibula.

A, Ankle joint is articulation between dome of talus (Ta) and distal tibia and fibula. Joint between distal tibia and fibula is called syndesmosis (bracket).

B, Plafond (dotted line) is transverse cortical articular surface at distal end of tibia. Mortise is rectangular opening consisting of plafond as well as inner cortical articular surfaces (solid lines) of medial malleolus (MM) and lateral malleolus (LM). Talar dome fits into ankle mortise like mortise-and-tenon joint in woodworking.

tine radiographs are usually sufficient. Intraarticular fractures through the tibial plafond often require surgical open reduction and internal fixation (ORIF) to restore the anatomic alignment of the articular surfaces, and multiplanar reformatted CT scans are instrumental in surgical planning. I will discuss the three distal tibial fractures that typically come to CT: the pilon fracture in adults and the juvenile Tillaux and triplane fractures in adolescents.

CT

At the University of Wisconsin in Madison, my colleagues and I have developed our “F/A/T” CT protocol—that is, a single scanning protocol that allows us to create multiplanar reformatted images optimized to visualize the foot, ankle, and distal tibia (F/A/T). A discussion of our CT techniques is beyond the scope of this chapter, but the latest versions of all of the musculoskeletal protocol sheets for the University of Wis-



Fig. 2—Non-weight-bearing radiographic ankle series in 37-year-old man with lateral ankle pain after acute inversion injury.

A and B, Anteroposterior (A) and mortise (B) views show normal appearance of ankle joint.

C, Lateral ankle view reveals no abnormalities of hind foot. Region outlined by dashed rectangle is magnified and displayed to right. Close inspection of base of fifth metatarsal on lateral view of ankle reveals proximal diaphyseal fracture, so-called “Jones fracture” (arrow). Fractures of base of fifth metatarsal often present clinically as lateral ankle pain. Technologists must be careful to include base of fifth metatarsal on at least one view of all ankle radiographic series.

consin can be viewed and downloaded free of charge at www.Radiology.Wisc.Edu/MSKprotocols.

Radiography

Ankle radiographs can be obtained with the patient either weight-bearing or non-weight-bearing, depending on the preference of the ordering clinician. A standard radiographic ankle series consists of three projectional views: anteroposterior (AP), mortise, and lateral (Fig. 2). The mortise view is similar to the AP view, but the leg internally is rotated 15° to better profile the ankle mortise.

When obtaining radiographs of the ankle, the technologist should include the base of the fifth metatarsal on at least one view. Fractures of the base of the fifth metatarsal clinically present with the patient complaining of lateral ankle pain, and this presentation can cause the clinician to request radiographs of the ankle rather than of the foot. Figure 2C is such a case in which the Jones fracture (Appendix 1) can be seen at the edge of the lateral view.

Classification Schemes

Over the centuries, many classification schemes have been devised to describe malleolar fractures and their relationship to the ankle ligaments. As early as 1768, Sir Percivall Pott, in his article “Some Few General Remarks on Fractures and Dislocations” [2], described a fracture of the fibula 2–3 inches (5–8 cm) above the tip associated with a tear of the deltoid ligament and lateral subluxation of the talus [3]. The term “Pott’s fracture” has been applied to bimalleolar fractures, but this term is a misnomer because the fracture Pott described involved neither malleolus (Appendix 2).

In the 19th century, most of the writings about ankle injuries originated from authors in France. In 1816, Dupuytren (Ap-

pendix 3) experimented with cadavers to produce ankle fractures [4, 5]. Subsequent French authors classified Dupuytren’s fractures as low if the fibular fracture was at the level of the syndesmotic ligaments or as high if the fracture was at the junction of the middle and distal thirds of the fibula accompanied by disruption of the syndesmosis.

The most meticulous and comprehensive classification of ankle injuries was developed by the prominent Danish surgeon Niel Lauge-Hansen (1899–1976). Between 1948 and 1956, he published a series of five articles describing five basic mechanisms of ankle injury [6–10]. The Lauge-Hansen classification scheme uses two-word descriptors. The first word describes the initial position of the foot at the time of injury: in either supination or pronation. The second word describes the injuring force acting through the talus: adduction, abduction, eversion, or dorsiflexion. Thus, Lauge-Hansen classified ankle fractures as follows: supination-adduction, supination-eversion, pronation-eversion, pronation-abduction, and pronation-dorsiflexion; each of these five main types were further classified into two to four substages. Lauge-Hansen thought that it was important to understand the exact mechanism of ankle injuries because he believed that closed reduction of the ankle fractures should be based on a reversal of the injuring forces in exact inverse order to that in which they occurred. This philosophy has not stood the test of time and, for most of us, the Lauge-Hansen system is not used to communicate our radiographic findings to orthopedic surgeons.

A more practical system for classifying ankle fractures was first introduced by Robert Danis in 1949 [11], and it was modified by Bernhard Georg “Hardy” Weber in 1972 [12]. The Danis-Weber classification is based on the premise that the higher the fibular fracture, the greater the syndesmotic injury, likelihood of displacement, and need for ORIF.

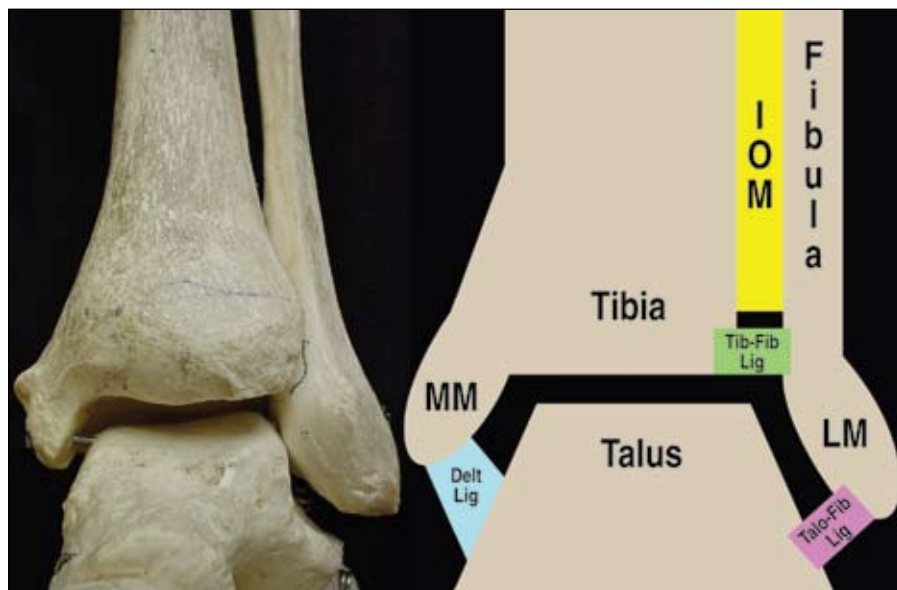
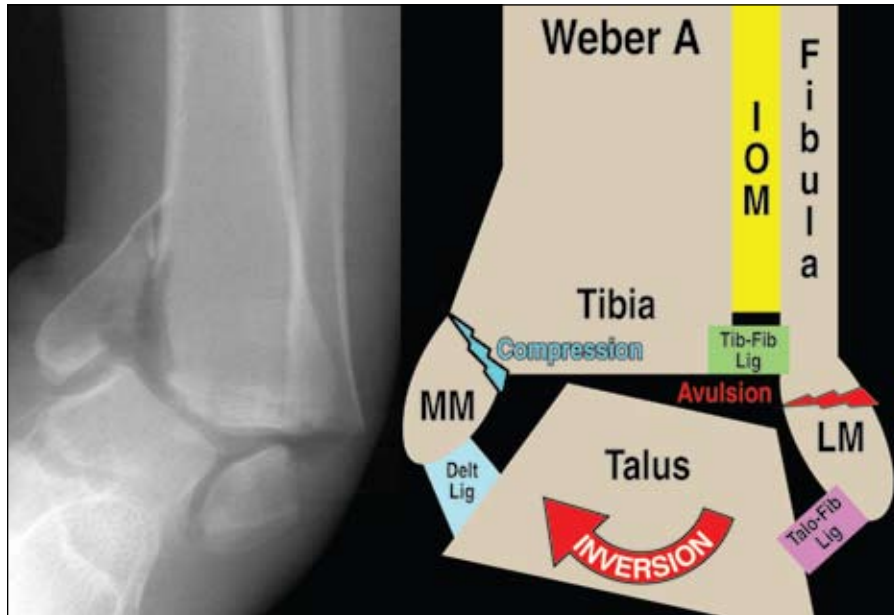


Fig. 3—Two models of ankle mortise. Skeleton on left shows relationship of talus to malleoli and syndesmosis. On right is same anatomy using simple shapes. Intraosseous membrane (IOM) is shown in yellow. Syndesmotic ligaments and anterior and posterior tibiofibular ligaments (Tib-Fib Lig) are modeled in green. Anterior and posterior talofibular ligaments (Talo-Fib Lig) are modeled in purple. Deltoid ligament (Delt Lig) is shown in blue. MM = medial malleolus, LM = lateral malleolus.

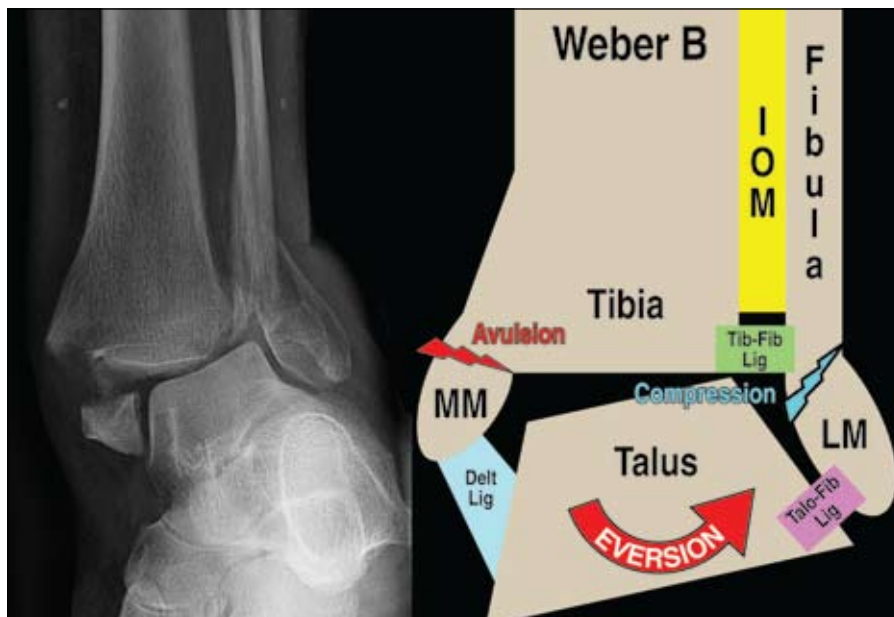
Weber fractures—Figure 3 shows two models of the ankle mortise. On the left is a skeleton model showing the relationship of the talus to the malleoli and syndesmosis, and on the right is the same anatomy modeled using simple shapes. The tibia is connected to the fibula by the intraosseous membrane (IOM), a sheet of connective tissue that runs along the length of the diaphyses. Where the distal fibula fits into a groove in the distal tibia is the syndesmosis. The syndesmotic ligaments—that is, the anterior and posterior tibiofibular ligaments—main-

tain the integrity of this syndesmotic joint. The integrity of the ankle joint is maintained laterally by the anterior and posterior talofibular ligaments and medially by the deltoid ligament.

Figure 4 illustrates how either inversion or eversion rotational injuries to the talus cause both avulsive and compressive forces on the malleoli. Figure 4A illustrates a Weber type A injury radiographically on the left and mechanistically on the right. As the talus undergoes an inversion rotational injury, it applies avulsive pulling forces on the lateral side of the



A



B

Fig. 4—Weber fractures. Intraosseous membrane (IOM) is shown in yellow. Syndesmotic ligaments and anterior and posterior tibiofibular ligaments (Tib-Fib Lig) are modeled in green. Anterior and posterior talofibular ligaments (Talo-Fib Lig) are modeled in purple. Deltoid ligament (Delt Lig) is shown in blue. MM = medial malleolus, LM = lateral malleolus.

A, Weber type A. Anteroposterior (AP) radiograph (*left*) of ankle in 23-year-old woman shows medial displacement of talus relative to tibia: horizontal avulsion fracture through lateral malleolus and vertically oriented compression fracture through medial malleolus. Model on right shows mechanism of Weber type A ankle fracture: As talus undergoes inversion rotational injury, it applies avulsive pulling forces on lateral side of mortise and compressive pushing forces on medial side.

B, Weber type B. Anteroposterior (AP) radiograph (*left*) of ankle in 79-year-old woman shows lateral displacement of talus relative to tibia, horizontal avulsion fracture through medial malleolus, and obliquely vertically oriented compression fracture through distal fibula, below level of syndesmosis. Model on right shows mechanism of Weber type B ankle fracture. As talus undergoes eversion rotational injury, it applies avulsive pulling forces on medial malleolus and compressive pushing forces on fibula.

(Fig. 4 continues on next page)

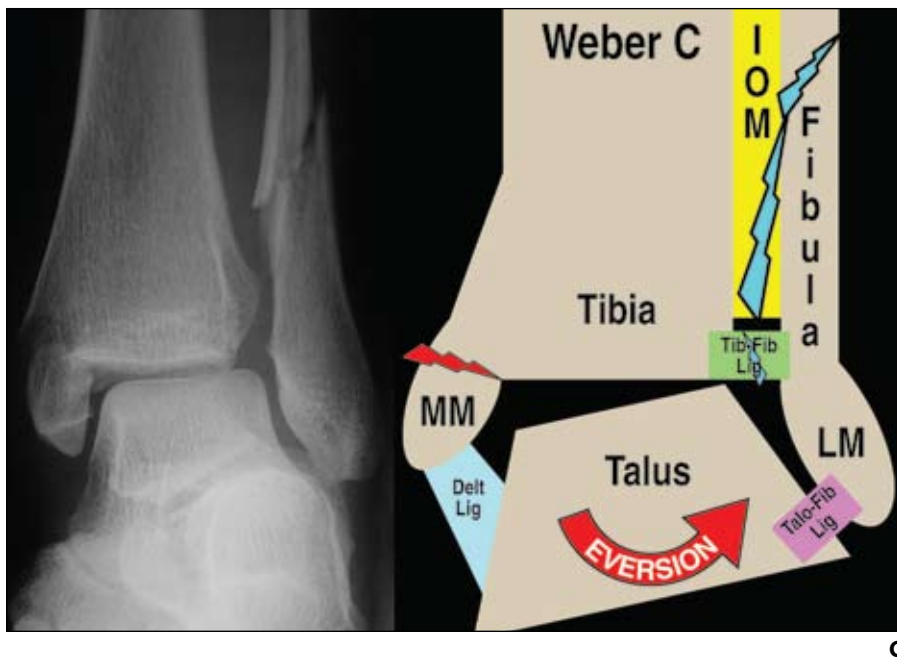


Fig. 4 (continued)—Weber fractures. Intraosseous membrane (IOM) is shown in yellow. Syndesmotic ligaments and anterior and posterior tibiotalar ligaments (Tib-Fig Lig) are modeled in green. Anterior and posterior talofibular ligaments (Talo-Fib Lig) are modeled in purple. Deltoid ligament (Delt Lig) is shown in blue. MM = medial malleolus, LM = lateral malleolus.
C, Weber type C. AP radiograph (left) of ankle in 30-year-old woman shows horizontal avulsion fracture through medial malleolus and obliquely vertically oriented compression fracture through distal fibula, above level of syndesmosis. Syndesmosis is disrupted and abnormally widened, with no overlap between tibia and fibula. Model on right shows mechanism of Weber type C ankle fracture. Mechanism of injury is same as Weber type B except compressive force extends through syndesmosis, tearing tibial fibular ligaments and distal IOM, with oblique fracture higher up on fibula. If compressive force extends proximally up length of IOM, fracturing through proximal fibula up near knee, then this is referred to as “Maisonneuve fracture” (not illustrated).

mortise and compressive pushing forces on the medial side. The lateral avulsive forces may sprain or tear the talofibular ligaments or they may cause an avulsion fracture through the lateral malleolus, pulling it off the fibular shaft. Conversely, the compressive forces on the medial side can fracture through the medial malleolus, pushing it away from the tibial plafond. Radiographically, avulsion fractures can be distinguished from compression fractures by the orientation of the fracture margins. Avulsion fractures are horizontally oriented, in a direction roughly perpendicular to the lines of force. Compression fractures are more obliquely or vertically oriented—that is, in the same direction as the force. This principle is key to understanding the Weber fractures.

Figure 4B illustrates a Weber type B injury radiographically on the left and mechanistically on the right. Here, the talus is undergoing an eversion rotational injury, with the avulsive pulling forces on the medial malleolus and the compressive pushing forces on the lateral side. The medial avulsive forces may sprain or tear the deltoid ligament or may cause a horizontal avulsion fracture through the medial malleolus. The compressive forces on the lateral side cause a vertically

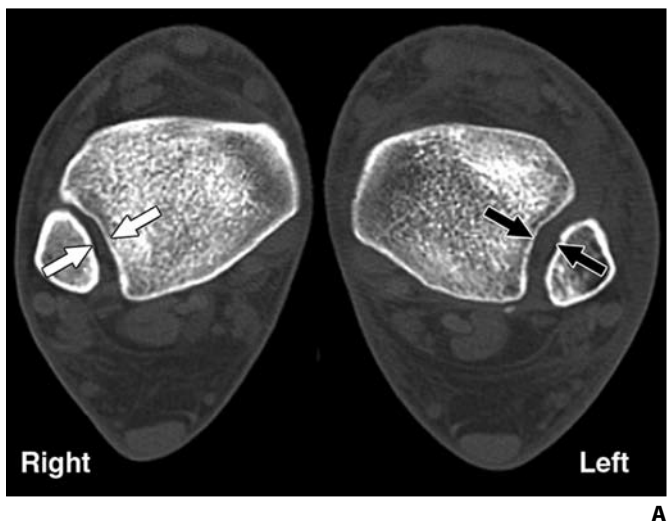


Fig. 5—CT of Weber type C in 34-year-old man.
A, Axial images through both ankles show abnormally widened left syndesmosis (black arrows) as compared with width of contralateral normal right syndesmosis (white arrows).
B, Mortise coronal image shows widened syndesmosis (black arrows) and high fibula fracture (white arrow), characteristic of Weber type C.

oblique fracture through the fibula. If the fibular fracture is distal to the syndesmosis, it is characterized as a Weber type B. The syndesmotic ligaments and IOM remain intact.

Figure 4C illustrates a Weber type C injury radiographically on the left and mechanistically on the right. This injury is caused by the same mechanism as a Weber type B injury except the compressive lateral force extends through the syndesmosis, tearing the tibiofibular ligaments as well as the distal IOM. In this case, the obliquely oriented fibula fracture will be higher—above the level of the syndesmosis. Identifying this high fibula fracture is key to recognizing that the syndesmotic ligaments are disrupted because radiographically the syndesmosis may not appear abnormally widened if not stressed.

Indeed, sometimes the fibula fracture is so high that it occurs through the proximal fibula, near the knee joint, and is thus not imaged on ankle radiographs. This fracture is referred to as a “Maisonneuve fracture” (Appendix 4) and can be suspected when ankle radiographs show an avulsion fracture through the medial malleolus without an accompanying fibula fracture. If you cannot determine from ankle radiographs if you are look-

ing at a Weber type B or Weber type C injury, this is a clue that you may be looking at a Maisonneuve fracture, and radiographs that include the entire length of the fibula should be obtained.

Determining the integrity of the syndesmosis is an important surgical consideration because syndesmotic injuries usually require screw fixation. In cases in which the integrity of the syndesmosis is unclear based on physical examination and radiographs, CT scans can be helpful (Fig. 5). Scanning in the axial plane through both ankles allows simultaneous side-by-side comparison of the widths of the injured and uninjured syndesmoses.

Pilon fractures—Pilon fractures refer to any tibial fracture that involves the distal articular plafond and are typically the result of an axial loading force [13]. “Pilon” is French for pestle, an instrument used for crushing or pounding, and was first used to describe this fracture in 1911 by Étienne Destot [14], the father of radiology in France. When pilon fractures are the result of a high-energy injury, such as a fall from a height or a high-speed motor vehicle front-end collision, they can produce significant comminution with multiple displaced fracture

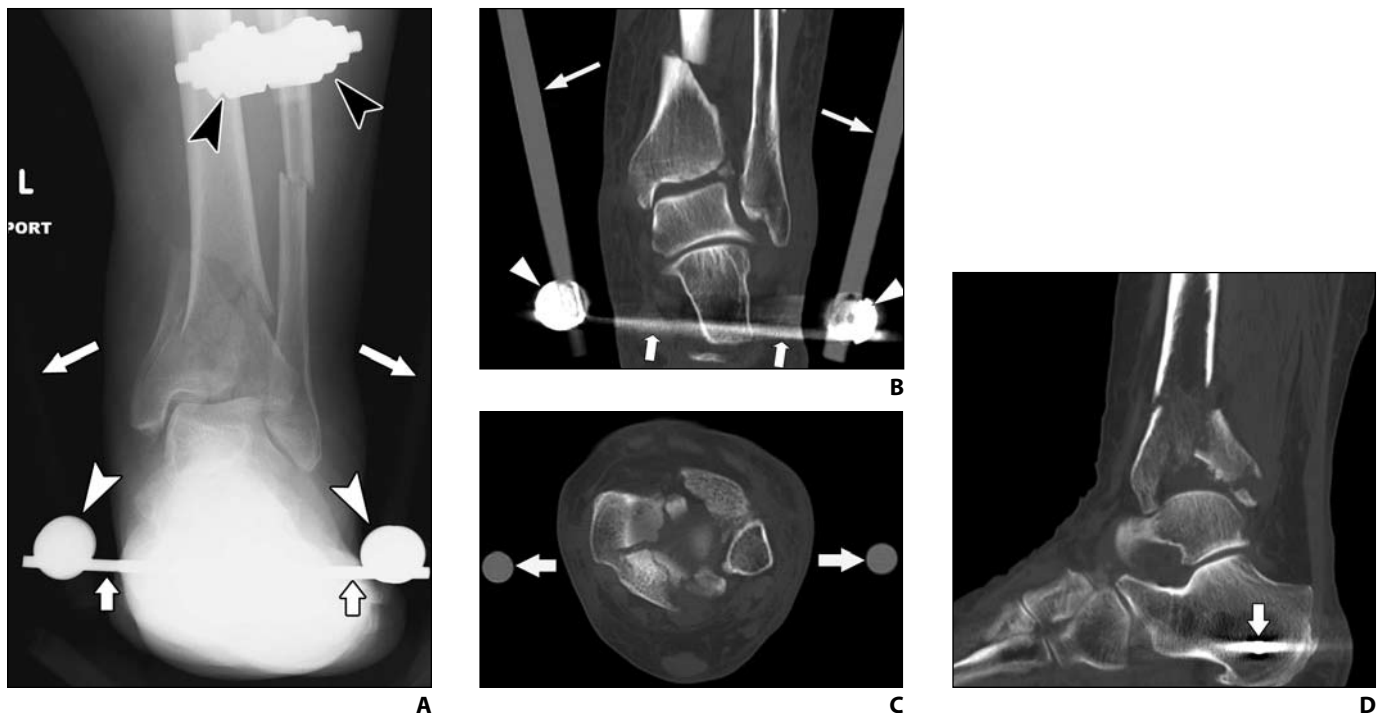


Fig. 6—Pilon fracture in 64-year-old woman.

A, Anteroposterior (AP) radiograph shows external fixation device. Radiopaque hardware that could potentially cause streak artifacts—thick metal pin through calcaneus (*short white arrows*), distal pin–bar clamps (*white arrowheads*), and proximal pin–bar clamps (*black arrowheads*)—are below and above pilon fracture and thus are not in axial CT scanning plane though fracture. Longitudinal carbon fiber–connecting bars (*long white arrows*) are barely radiopaque and, as such, are barely discernible on this radiograph. These bars will not cause streak artifacts on CT.

B, CT image reformatted in coronal plane. Carbon fiber–connecting bars (*long white arrows*) cause no CT streak artifacts across fractures. CT streak artifacts from metal percutaneous pin (*short white arrows*) and pin–bar clamps (*arrowheads*) are all distal to pilon fracture and affect visualization of calcaneus cortex only minimally.

C, CT image in axial plane through level of fractured plafond. Carbon fiber–connecting bars (*arrows*) cause no CT streak artifacts across fractures.

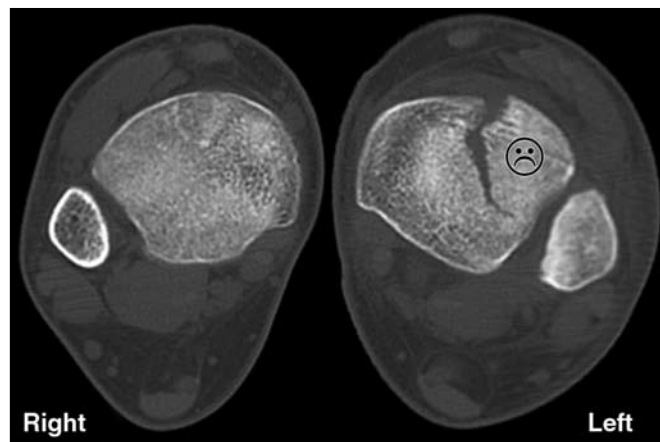
D, CT image in sagittal plane shows talar dome is impacted into large cortical gap in plafond. Surgeon needs this visual information to plan open reduction and internal fixation. Arrow shows percutaneous pin passing through calcaneus.

Fig. 7—Juvenile Tillaux fracture in 13-year-old girl who reported hearing or feeling snap when, during cheerleading, she landed very forcefully on left foot with ankle twisted. Salter-Harris type 3 fracture was seen on radiographs obtained at outside institution (not shown). CT was requested to assess degree of fracture displacement.

A, Axial CT image through both distal tibial physes shows avulsion fracture of left anterior lateral quadrant (*frowny face*).

B, Coronal CT image shows this Salter-Harris type 3 fracture with longitudinal component through epiphysis (*arrow*) and transverse component through unfused lateral physis (*white arrowheads*). Fused medial physis is indicated by black arrowheads.

C, Sagittal CT image shows this Salter-Harris type 3 fracture with longitudinal component through epiphysis (*arrow*) and transverse component through unfused physis (*arrowheads*). Because CT shows fracture fragments are displaced more than 2 mm, open reduction and internal fixation were performed electively 1 week after injury. Postoperatively, patient did well after being non-weight-bearing in cast for 6 weeks and in weight-bearing boot for 4 weeks.



A

fragments. Although these comminuted fractures invariably require internal fixation, they are typically not surgical emergencies. Patients with significantly displaced fractures may undergo surgery the day of the injury for traction reduction and external fixation to restore relative alignment to the mortise and then may wait several days for the swelling of the surrounding soft tissues to reduce before undergoing the more anatomic ORIF of the pilon fracture. As a result, patients with a pilon fracture typically undergo CT during that interim period, after the external fixator is in place and before ORIF. However, as illustrated in Figure 6, such external fixation hardware is not an impediment to obtaining the CT images that the surgeon needs.

To maintain alignment between the hindfoot and leg, the surgeon will percutaneously drill thick metal pins through the calcaneus (short white arrows in Figs. 6A, 6B, and 6D) and through the tibia proximal to the fracture (the proximal pin is not seen in Fig. 6). The pins are rigidly attached via metal clamps (arrowheads in Figs. 6A and 6B) to nonmetallic connecting bars (long white arrows in Figs. 6A–6C). The nonmetallic bars span the length of the fracture and maintain the tibia length. Because the nonmetallic bars are made of materials, usually carbon fiber, that block very few X-rays from reaching the detectors, they are barely radiopaque and cause no streak artifacts on CT (Fig. 6C). The metal pin–bar clamps block many X-rays from reaching detectors and thus cause some CT streak artifacts. However, because the clamps are always placed proximal and distal to the pilon fracture, they never cause CT streak artifacts across the reformatted fracture margins (Figs. 6B and 6D). Using our standard bone CT protocol of thin and overlapping slices, metallic streak artifacts are often not visible. Notice the good visualization of the calcaneus cortex in Figures 6B and 6D, which is only minimally affected by streaking caused by the metal pin–bar clamps.

Juvenile Tillaux fractures—Juvenile Tillaux fractures are Salter-Harris type 3 fractures [15] (Appendix 5). These fractures have a very characteristic appearance, particularly on CT. The fracture is the result of an external rotation force



B



C

pulling on the anterior tibiofibular ligament, causing avulsion of the anterior lateral corner of the distal tibial epiphysis (Fig. 7A). These fractures always occur laterally because the distal tibial physis fuses from medial to lateral as a child matures (Fig. 7B). As such, juvenile Tillaux fractures occur exclusively in adolescents whose lateral growth plates have

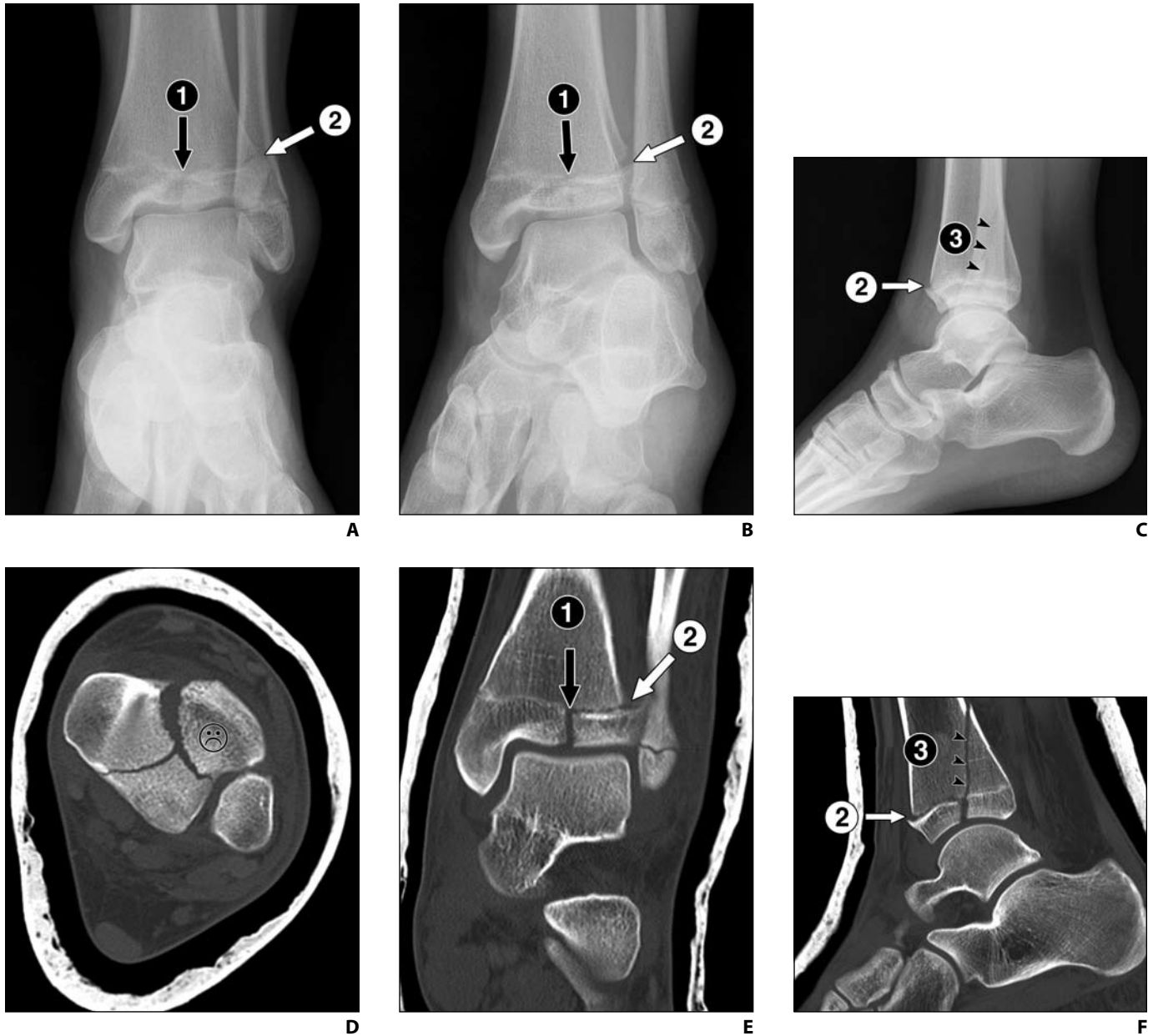


Fig. 8—Triplane fracture in 13-year-old girl who twisted ankle in sledding accident.

A and B, Non-weight-bearing anteroposterior (**A**) and mortise (**B**) radiographs. When minimally displaced, fracture margins can be difficult to see on radiographs. Black arrow points to epiphysis fracture, running vertically in sagittal plane (plane 1). White arrow points to physis fracture, running horizontally in axial plane (plane 2).

C, Lateral non-weight-bearing radiograph. Arrow points to physis fracture, running horizontally in axial plane (plane 2). Arrowheads point to metaphysis fracture, running obliquely vertically in coronal plane (plane 3). This CT scan was obtained after closed reduction and casting to assess degree of fracture displacement.

D, Axial CT shows avulsion fracture of anterior lateral quadrant (*frown face*) that resembles juvenile Tillaux (Fig. 7A). Surrounding plaster cast causes no streak artifacts and helps to immobilize patient's ankle during scanning.

E, Coronal CT image. Black arrow points to epiphysis fracture, running vertically in sagittal plane (plane 1). White arrow points to physis fracture, running horizontally in axial plane (plane 2).

F, Sagittal CT image. White arrow points to physis fracture, running horizontally in axial plane (plane 2). Black arrowheads point to metaphysis fracture, running obliquely vertically in coronal plane (plane 3). These images clearly show surgeons what they need to know—that is, closed reduction still had unacceptable displacement, and open reduction and internal fixation were performed the next day. Postoperatively, patient was non-weight-bearing in cast for 4 weeks and was pain free after 1 week in walking boot.

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not yet fused, usually between the ages of 12 and 15 years. Coronal and sagittal images are useful in showing the degree of displacement, particularly at the articular surface (arrows in Figs. 7B and 7C). Although minimally displaced juvenile Tillaux fractures are usually treated nonoperatively, fractures displaced more than 2 mm should have orthopedic consultation and surgery to restore the congruity of the joint surface.

Triplane fractures—Triplane fractures are Salter-Harris type 4 fractures [16]. Like the juvenile Tillaux fracture, triplane fractures occur in adolescents whose lateral growth plates have not yet fused. When minimally displaced, triplane fractures can be difficult to see radiographically, and frontal and lateral views are required to depict their multiplanar nature (Figs. 8A–8C): The epiphysis fracture runs vertically in a sagittal orientation (plane 1), the physeal fracture runs horizontally in the axial plane (plane 2), and the metaphyseal fracture runs obliquely vertically in a coronal orientation (plane 3). Multiplanar CT scans are ideally suited to visualize these fractures in all planes (Figs. 8D–8F) and often reveal more deformity of the articular surface than would be anticipated from radiographs alone.

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APPENDIX 1: Sir Robert Jones

Sir Robert Jones (1857–1933) was the father of orthopedic surgery in England and revolutionized the care of wounded soldiers during World War I. An early proponent of X-rays, Jones imaged the transverse extraarticular fracture across the proximal diaphysis of the fifth metatarsal just a few months after Wilhelm Röntgen [17] published “A New Kind of Ray,” December 28, 1895. Jones first described this fracture after having sustained such an injury himself “while dancing.” (This was not ballroom dancing; rather, it was “dancing in a circle round the tent pole” with his military colleagues. There was no mention as to whether alcohol was involved.) He subsequently identified this fracture on radiographs of two other patients and published his series of three patients in the *Annals of Surgery* in 1902 titled “Fracture of the Base of the Fifth Metatarsal Bone by Indirect Violence” [18].

APPENDIX 2: Sir Percivall Pott

It seems more likely that “Pott’s fracture” refers to the compound tibial fracture Sir Percivall himself sustained in 1756 when he fell from his horse while riding to see a patient. The surgeon who attended him advised amputation and Pott agreed. However, at the last moment Pott’s tutor, Edward Nourse, advocated a trial of setting and splinting and amazingly Pott survived. Sir Percivall is perhaps better remembered for his descriptions of tuberculosis of the spine, “Pott’s disease,” and of the extradural abscess that can result from frontal sinusitis, middle ear disease, or compound fractures, “Pott’s puffy tumor” [19–21].

APPENDIX 3: Baron Guillaume Dupuytren

Baron Guillaume Dupuytren (1777–1835) was considered by many, including himself, to be the greatest French surgeon of the 19th century. His patients included Louis XVIII, Charles X, and Napoleon I, and his students included Lisfranc and Maisonneuve.

APPENDIX 4: Jules Germain François Maisonneuve

Jules Germain François Maisonneuve (1809–1897), a French surgeon and a student of Guillaume Dupuytren, was the first to describe external rotation as a contributing mechanism in the production of ankle fractures.

APPENDIX 5: Salter-Harris Classification System

The Salter-Harris system is applied to fractures that involve the growth plate (physis) at the ends of skeletally immature bones. Type 1 refers to simple transverse fractures that involve the physis only. Type 2 is the most common and refers to a fracture that involves the physis and the adjacent metaphysis. Type 3 fractures extend from the physis through the epiphysis at the end of the bone, typically disrupting the articular surface at a joint. Type 4 fractures involve the epiphysis, the physis, and the metaphysis. Type 5 fractures are rare and are crush injuries to the growth plate.
