Abstract

This article reviews the anatomy of the ankle joint and illustrates the common ankle injuries imaged emergently via radiographs and CT, including these fractures: Weber, pilon, juvenile Tillaux and triplane.

Introduction

This article is written as a handout to accompany my lecture on ankle trauma, presented as part of the "Categorical Course: Emergency and Trauma" at the 108th annual meeting of the American Roentgen Ray Society meeting held in Washington DC on 4/17/08. For a more complete discussion of CT & MR of the Ankle & Foot I suggest you read my chapter in Haaga's two-volume text, "CT and MR Imaging of the Whole Body"[1] You can download this chapter, as well as my other lecture materials on musculoskeletal imaging… and on PowerPoint… 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 (figure 1a). Ankle joint is the preferred name of this joint in the radiology and orthopedic surgery literature, rather than "tibia-talar" or "crural" joint. The flat talar dome articulates with the flat surface at the distal end of the tibia known as the **plafond** (figure 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, 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 domes fits, analogous to a mortise and tenon joint in woodworking. The ankle mortise is a remarkably sturdy joint. Just like the hip and knee joints, the ankle just must bear our entire body weight with every step. But while 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 syndesmotic joint is held together by thick connective ligaments. Most other joints in the body, including the ankle and sub-talar joints, are synovial joints in that they are enclosed by a synovial 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 (figure 5a).

Imaging ankle trauma in the emergency department

All ankle imaging should begin with radiographs, and for common twisting injuries such as the Weber fractures I will be discussing, routine radiographs are usually sufficient. Intra-articular fractures through the tibial plafond often require surgical open reduction and internal fixation (ORIF) in order to restore the anatomic alignment of the articular surfaces, and multi-planar reformatted CT scans are instrumental in such 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. At the University of Wisconsin in Madison we have developed our "F/A/T" CT protocol – a single scanning protocol that allows us to create multi-planar reformatted images optimized to visualize the foot / ankle / distal tibia. A discussion of our CT scanning techniques are beyond the scope of this chapter, but the latest versions of all the UW

Musculoskeletal protocol sheets can be viewed and downloaded for free at: www.Radiology.Wisc.Edu/MSKprotocols.

Radiographs

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

When shooting radiographs of the ankle, it is important that the technologist includes the base of the 5th metatarsal on at least one view. Fractures of the base of the 5th metatarsal clinically present with the patient complaining of lateral ankle pain, and this can cause the clinician to request radiographs of the ankle rather than of the foot. Figure 2c is such a case where the Jones[*] fracture can be seen at the edge of the lateral view.

Classification schemes

Over the centuries there have been many classification schemes 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", described a fracture of the fibula 2-3 inches above the tip associated with a tear of the deltoid ligament and lateral subluxation of the talus.[2] The term "Pott's fracture" has been applied to bimalleolar fractures, but this is a misnomer as the fracture Pott described involved neither malleolus.[†]

In the 19th century much of the writings about ankle injuries came out of France. In 1816, Dupuytren[‡] experimented with cadavers to produce ankle fractures.[3,4] Subsequent French authors described classified Dupuytren fractures as *low* if the fibular

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[*] Sir Robert Jones (1857-1933) was the father of orthopædic surgery in England and revolutionized the care of wounded soldiers during World War I. An early proponent of x-rays, Jones imaged the transverse, extra-articular fracture across the proximal diaphysis of the 5th metatarsal just a few months after Röntgen published "On a New Kind of Rays," December 28, 1895. Jones first described this fracture after having sustained such an injury himself "whilst 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 in the Annals of Surgery in 1902, "Fracture of the Base of the Fifth Metatarsal bone by Indirect Violence".

[†] 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. But 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 TB of the spine, "Potts Disease", and of the extradural abscess that can result from frontal sinusitis, middle ear disease, or compound fractures, "Potts puffy tumor".
www.surgical-tutor.org.uk/surgeons/pott.htm
www.surgeons.org.uk/history-of-surgeons/percival-pott.html
http://www.aim25.ac.uk/cgi-bin/search2?coll_id=5604&inst_id=6

[‡] 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.

fracture was at the level of the syndesmotic ligaments, or *high* – 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[5,6,7,8,9] describing five basic mechanism of ankle injury. The Lauge-Hansen classification scheme uses 2 words descriptors. The first word describes the initial position of the foot at the time of injury: either in 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: **supination-adduction**, **supination-eversion**, **pronation-eversion**, **pronation-abduction**, and **pronation-dorsiflexion**; with each of these 5 main types being further classified into two to four sub-stages. Lauge-Hansen felt it was important to understand the exact mechanism of ankle injuries, for 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 our orthopedic surgeons.

A more practical system for classifying ankle fractures was first introduced by Robert Danis in 1949,[10] and modified by Bernhard Georg "Hardy" Weber in 1972.[11] 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.

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. On the right is this same anatomy modeled using simple shapes. The tibia is connected to the fibula by the intra-osseous 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, the anterior and posterior tibial-fibular ligaments, maintain the integrity of this syndesmotic joint. The integrity of the ankle joint is maintained laterally by the anterior and posterior talo-fibular 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 mortise, and compressive pushing forces on the medial side. The lateral avulsive forces may sprain or tear the talo-fibular ligaments, or they may cause an avulsion fracture through the lateral malleolus, pulling if off of 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, 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 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 is the same mechanism as a Weber type B injury, except now the compressive lateral force extends through the syndesmosis, tearing the tibial-fibular ligaments as well the distal IOM. In this case the obliquely oriented fibula fracture will be higher up, above the level of the syndesmosis. *Identifying this high fibula fracture is key to recognizing that the syndesmotic ligaments are disrupted*, as 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, up near the knee joint, and is thus not imaged on the ankle radiographs. This is referred to as a Maisonneuve[‡] fracture, and can be suspected when the ankle radiographs demonstrate an avulsion fracture through the medial malleolus without an accompanying fibula fracture. If you cannot tell from ankle radiographs if you are looking at a Weber type B or C, this is a clue that you may be looking at a Maisonneuve, and radiographs that include the entire length of the fibula should be obtained.

Determining the integrity of the syndesmosis is an important surgical consideration, as syndesmotic injuries usually require screw fixation. In cases when the integrity of the syndesmosis is unclear based upon physical exam and radiographs, a CT scan can be helpful (figure 5). Scanning in the axial plane through both ankles simultaneously allows for side-by-side comparison of the widths of the injured and uninjured syndesmoses.

Pilon fractures[12]

Pilon fractures refer to any tibial fracture that involves the distal articular plafond, and are typically the result of an axial loading force. 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, the father of radiology in France. When they are the result of a high-energy injury, such as a fall from height or a high-speed motor-vehicle front-end collision, pilon fractures can produce significant comminution with multiple displaced fracture fragments. And while these comminuted fractures invariably require internal fixation, they are typically not surgical emergencies. Patients with significantly displaced fractures may go to the operating room (OR) the day of the injury for traction reduction and external fixation to restore relative alignment to the mortise, and then wait several days for the swelling of the surrounding soft tissues to reduce before returning to the OR for the more anatomic ORIF of the pilon fracture. This means these patients typically receive their CT scans during this interim period, after the external fixator is in place. However, as illustrated in figure 6, such external fixation hardware is no

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[‡] 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.

impediment to obtaining the CT images the surgeon requires.

To maintain alignment between the hindfoot and leg the surgeon will percutaneously drill thick metal pins through the calcaneus (white arrows in figure 6a/b/d) and through the tibia proximal to the fracture (this pin is not seen in figure 6). These pins are rigidly attached via metal clamps (arrowheads in figure 6a/b) to non-metallic connecting bars (gray arrows in figure 6a/b/c). It is these non-metallic bars that span the length of the fracture and maintain the tibia length. Since these non-metallic 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 CT streak artifacts (figure 6c). The metal pin-bar clamps will block many x-rays from reaching detectors and thus will cause some CT streak artifacts. However, as the clamps are always placed proximal and distal to the pilon fracture, they never cause any CT streak artifacts across the reformatted fracture margins (figure 6b/d). Using our standard bone CT scanning protocol of thin/overlapping slices, metallic streak artifacts are often not appreciable. Notice the good visualization of the calcaneus cortex in figure 6b/d which is only minimally affected by streaking caused by the metal pin-bar clamps.

Juvenile Tillaux fractures[13]

Juvenile Tillaux fractures are Salter-Harris type 3 fractures[*]. These fractures have a very characteristic appearance, particularly on CT. The fracture is the result of an external rotation force pulling on the anterior tibiofibular ligament, causing avulsion of the anterior-lateral corner of the distal tibial epiphysis (figure 7a). These fractures always occur laterally because the distal tibial physis fuses from medial to lateral as a child matures (figure 7b). As such, juvenile Tillaux fractures occur exclusively in adolescents who have not yet fused their lateral growth plates, usually between the ages of 12 and 15 years-old. Coronal and sagittal images are useful to demonstrate the degree of displacement particularly at the articular surface (white arrows). While minimally displaced juvenile Tillaux fractures are usually treated non-operatively, fractures displaced more than 2 mm should have orthopedic consultation and surgery to restore the congruity of the joint surface.

Triplane fractures[14]

Triplane fractures are Salter-Harris type 4 fractures. Like the juvenile Tillaux fracture, triplane fractures occur in adolescents who have not yet fused their lateral growth plate. When minimally displaced, triplane fractures can be difficult to see radiographically, and require frontal and lateral views to appreciate their multiplanar nature (figure 8a/b/c): the epiphysis fracture running vertically in a sagittal orientation (plane 1), the physeal fracture running horizontally in the axial plane (plane 2), and the metaphyseal fracture running obliquely vertically in a coronal orientation (plane 3). Multi-planar CT scans are ideally suited to visualize these fractures in all planes (figure 8d/e/f), and often reveal more deformity of the articular surface than would be anticipated from radiographs alone.

[*] 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.

[1] www.Mosby.com ISBN 978-0-323-05375-4
[2] Wilson FC: Fractures of the Ankle: Pathogenesis and Treatment. J South Orthop Assoc 2000; 9(2). www.medscape.com/viewarticle/410433
[3] Dupuytren G. Of fractures of the lower extremity of the fibula and luxations of the foot. Med Classics 1939; 4:151-172.
[4] Peltier LF. Guillaume Dupuytren and Dupuytren's fracture. Surgery 1958; 43:868-874.
[5] Lauge-Hansen N. Fractures of the ankle. Arch Surg 1948; 56:259-317.
[6] Lauge-Hansen N. Fractures of the ankle II. Combined experimental-surgical and experimental-roentgenologic investigations. Arch Surg 1950; 60:957-987.
[7] Lauge-Hansen N. Fractures of the ankle. III. Genetic roentgenologic diagnosis of fractures of the ankle. AJR Am J Roentgenol 1954; 71:456-471.
[8] Lauge-Hansen N. Fractures of the ankle IV. Clinical use of genetic roentgen diagnosis and genetic reduction. Arch Surg 1952; 64:488-500.
[9] Lauge-Hansen N. Fractures of the ankle. V. Pronation-dorsiflexion fracture. Arch Surg 1953; 67:813-820.
[10] In: Danis R, eds. Theorie et pratique de l' osteosynthese. Paris, France: Masson & Cie, 1949.
[11] Weber BG. Die verletzungen des oberen sprunggelenkes 2nd ed. Bern, Switzerland: Huber, 1972.
[12] Borrelli J Jr, Ellis E, Pilon fractures: assessment and treatment, Orthop Clin North Am. 2002 Jan;33(1):231-45, x. Review.
[13] JM Protas and BA Kornblatt, Fractures of the lateral margin of the distal tibia. The Tillaux fracture, Radiology 1981; 138: 55.
[14] LF Rogers and AK Poznanski, Imaging of epiphyseal injuries, Radiology 1994; 191: 297.