Calcaneal Avulsion Fractures: An Often Forgotten Diagnosis

Sarah M. Yu1
Joseph S. Yu

OBJECTIVE. The calcaneus is the primary weight bearing bone in the heel, and its many surface contours render it a relatively difficult bone to visualize in its entirety. The stabilizing ligaments that hold the calcaneus in place occupy very specific locations, and the Achilles tendon enthesis is in a relatively constant location; therefore, avulsion fractures occur in reproducible locations.

CONCLUSION. The mechanisms of injuries include overuse and neuropathic conditions, although most cases are related to trauma.

The calcaneus is the largest bone in the foot and serves as the primary weight bearing structure in the heel. It is the initial striking surface of the foot during ambulation. The morphologic features of this bone are complex, and its many different surface contours function either as attachments to tendons, muscles, and ligaments or as sites of articulations. From a radiographic perspective, the calcaneus is a relatively difficult bone to visualize in its entirety. However, radiography remains the principal imaging modality for evaluating trauma to the calcaneus, the most frequently fractured tarsal bone. Most injuries are caused by high-energy trauma that result in intraarticular fractures [1]. However, 25% of fractures in adults are extraarticular, and the incidence is even higher in children [2, 3]. More than 90% of calcaneal fractures are extraarticular in children younger than 7 years, and 60% of such fractures are extraarticular in children 8–14 years old [4]. Extraarticular fractures are categorized as either compressive or avulsive types. Of the two types, avulsion fractures generally are more difficult to identify but are quite specific in their locations. In this article, we will show the characteristic appearance and location of these fractures, discuss the mechanisms responsible for these injuries, and illustrate potential pitfalls to consider.

Normal Anatomy

The calcaneus is a relatively long tarsal bone that has the shape of a pistol grip (Fig. 1). The bulbous proximal end is the calcaneal tuberosity, and it serves as the attachment of the Achilles tendon. It has two smaller inferior tubercles, the medial and lateral processes. The anterior part of the calcaneus is tapered distally. Superiorly, there are three articular facets covered by hyaline cartilage. These facets are oriented in slightly different geometric planes and articulate with the inferior aspect of the talus to form the anterior, middle, and posterior subtalar joints. The posterior talar facet has a triangular shape and a convex contour and is the largest of the three facets. Distal to the posterior subtalar joint is a depression called the calcaneal sulcus that extends medially to terminate at the sustentaculum tali. The middle talar facet is an inclined oval surface on the roof of the sustentaculum. The smaller oval-shaped anterior facet lies on the superomedial surface of the anterior calcaneus. Occasionally, the middle and anterior subtalar joints form a contiguous articulation instead of two discrete joints. Medially, the calcaneus is concave and relatively smooth. The flexor hallucis longus tendon courses in a groove beneath the sustentaculum. The fibular (peroneal) trochlea is a bony prominence in the inferior and anterior aspect of the lateral calcaneus that serves to separate the peroneal longus and brevis tendons. Anteriorly, the calcaneus is entirely covered with cartilage forming the surface that articulates with the cuboid.
Sites of Vulnerability

Achilles Tendon—Posterior Surface of the Calcaneal Tuberosity

The Achilles tendon is the strongest tendon in the body and has an average length of 15 cm. It begins at the midcalf level and it receives muscular fibers from three muscles: the medial and lateral heads of the gastrocnemius and the soleus muscles. Distally, the tendon has a concave anterior and convex posterior surface tapering to its broad enthesis on the calcaneus located at the middle third of the posterior surface of the calcaneal tuberosity. The width of the tendon at its insertion varies from 1.2 to 2.5 cm [5]. The tendon has a coiled collagen fiber pattern that spirals about 90° before its attachment [6]. This configuration gives it the viscoelasticity that allows it to absorb and adapt to forces that can approach 6–12.5 times body weight during running [7, 8].

Avulsion fractures of the calcaneal tuberosity are uncommon, accounting for 1.3–2.7% of calcaneal fractures [9]. Fractures of the tuberosity are either from an avulsion or shear-compression mechanism of injury, with the latter constituting most fractures. Avulsion may occur from sudden tension on the Achilles tendon from falling on a plantarflexed foot when the calf muscles are actively contracted, hyperextension of the ankle, or while pushing off a dorsiflexed foot such as in a sprinter beginning a race. There are four types of avulsion fractures (Fig. 2): type 1, simple avulsion with a variable-sized bone fragment (Fig. 3); type 2, beak fracture with a horizontal fracture extending into the posterior body; type 3, infrabursal avulsion by the superficial fibers of the middle third of the Achilles tendon (Fig. 4); and type 4, small beak fracture avulsed from the deep fibers of the tendon [9, 10]. Type 1 fractures are likely insufficiency fractures, occurring in elderly patients with osteoporosis after minor trauma such as tripping. In part, this is likely related to the regional vascular anatomy of the calcaneus [11]. In type 2 beak fractures, the tendinous attachment is more proximal than classically seen so that the avulsion involves only the proximal half of the tuberosity or because there is a separate more anterior contribution to the Achilles tendon by the soleus muscle [12, 13]. Types 3 and 4 fractures occur in younger people and require more-severe trauma. The cause is strong muscular contraction with the heel fixed to the ground and occurs only in a subset of patients who have a broad and extensive tendinous insertion [9].

An important pitfall is a neuropathic avulsion fracture of the tuberosity in a patient with long-term diabetes mellitus [13]. In these patients, the fracture occurs without a history of significant trauma or overuse activity. The primary fracture line is parallel to the apophyseal scar, and the fracture affects the superior cortex but not always the inferior cortex. The fracture also tends to extend posteriorly with a horizontal component immediately distal to the enthesis of the Achilles tendon [14]. When the fracture is imaged sequentially, distraction and fragmentation are common later findings. Neuropathic fractures are important because they have a much higher incidence of infection, non-union, malunion, and failure of fixation and require a much longer time to heal than non-neuropathic insufficiency fractures. Another pitfall occurs in children. A Salter 3 fracture of the apophysis in a skeletally immature patient may mimic Sever disease when it is not significantly displaced [15].

Plantar Fascia—Medial Process of the Calcaneal Tuberosity

The plantar fascia is a dense connective tissue band that resides in the inferior aspect of the foot and is composed of three cords: medial, central, and lateral cords. Biomechanically, the central cord is the most important component of the plantar fascia. It arises from the medial process of the calcaneal tuberosity and extends distally in a fanlike configuration, dividing into five distinct bands that interconnect with the plantar plates, plantar interdigital ligaments, and the sagittal septa underneath the metatarsophalangeal joints [16–18]. The fibers of the central cord envelop the aponeurosis of the flexor digitorum brevis muscle. The lateral cord arises from the lateral margin of the medial process and extends to the cuboid and base of the fifth metatarsal bone, enveloping the aponeurosis of the abductor digiti minimi muscle. The medial cord is very thin and invests the abductor hallucis muscle.

Conditions in the fascia that produce pain in the heel can be attributed to either plantar fasciitis or fascial rupture. Plantar fasciitis is the most common cause of heel pain, a degenerative process that results in fibrofatty degeneration, microtears, and collagen necrosis in the fascial enthesis. A rupture of plantar fascia is far less common but is characterized clinically by severe focal pain inferior to the calcaneus that is associated with tenderness to palpation and an acute onset [19, 20]. Fractures in the medial process of the calcaneus may occur as a result of compressive or tensile forces. The vast majority of fractures are due to compressive mechanisms such as striking the heel against a ledge or from a fall from a height so that the resulting fracture may herald a more complex fracture. Although rare, an avulsion of the medial plantar process may occur when forceful tension on the plantar fascia enthesis occurs during falling from a height while landing on the tips of the toes, from forceful contraction of the Achilles tendon against a static long plantar ligament, or from violent contraction of the abductor hallucis muscle by forced dorsiflexion of the first ray [21, 22]. The characteristic radiographic appearance is a small fleck of bone separated from the donor site in the inferior surface of the calcaneal tuberosity or a break in the medial process cortex (Fig. 5). Bone lysis at the enthesis may be the only finding in many cases (Fig. 6). A pitfall is a fracture through a plantar fascia enthesophyte, which may occur as a result of either direct trauma or forceful tension on the plantar fascia.

Bifurcate Ligament—Anterior Calcaneal Process

The anterior calcaneal process is a bony promontory in the anterolateral aspect of the calcaneus bordered distally by the navicular-cuboid articulation and proximally by the sinus tarsi. It forms the anterior facet superiorly and the calcaneocuboid joint anteriorly. The proximal attachment of the bifurcate ligament, an important stabilizer in plantar and dorsal flexion of the ankle, attaches to this process. The Y-shaped ligament with its two components, the calcaneonavicular and calcaneocuboid ligaments, is at its greatest tension when the ankle is inverted and plantar flexed [23]. Fractures involving the anterior process are not as common as other fractures in the ankle but they are not rare, occurring in as many as 5% of patients with ankle fractures [24–26]. Patients complain of swelling and dorsolateral pain over the sinus tarsi region. Because these fractures may be extremely difficult to detect, either CT or MRI is required to confirm the diagnosis in many cases, particularly when pain becomes chronic [23, 27, 28]. About half of these fractures are radiographically occult even when confirmed on MRI, whereas as many as 6% of radiographically evident fractures in adults are misdiagnosed as ankle sprains [23]. Reportedly, the percentage of unrecognized fractures in children is three to four times higher [4].
Calcaneal Avulsion Fractures

The two mechanisms of injury that result in a fracture of the anterior calcaneal process are compression or impaction forces and extreme tensile forces [29]. A compressional fracture occurs by impaction of the anterior process from the cuboid and talus during eversion and dorsiflexion, which is referred to as a “nutcracker” lesion, or by forceful abduction of the forefoot with the heel fixed to the ground [30, 31]. An avulsion fracture is caused by tension on the bifurcate ligament during forceful inversion and plantar flexion of the foot. In fact, this fracture constitutes the most common avulsion fracture affecting the calcaneus [26]. In general, impaction fractures tend to be larger than avulsion fractures. These fractures are important because they have a strong association with other foot abnormalities, such as rupture of the anterior talofibular ligament, other tarsal fractures, and injuries of the peroneal tendons [29, 32]. A lateral radiograph of the ankle offers the most optimal opportunity for identifying the fracture, which characteristically appears vertically through the process (Fig. 7). Careful scrutiny of the cortex is necessary for making the diagnosis. If the lateral view is equivocal, an oblique projection of the foot may be diagnostic [24]. Anterior process fractures are classified into three types: type 1 fractures are small (< 1 cm) and non-displaced, type 2 fractures have minimal (2 mm) displacement and no involvement of the calcaneocuboid joint, and type 3 fractures are comminuted or large with involvement the calcaneocuboid joint (> 25%) [31]. Types 1 and 2 fractures usually are avulsive, whereas most type 3 fractures are compressive. A pitfall is a normal small ossicle, the os calcaneus secondary, which is adjacent to the anterior calcaneal process mimicking this fracture; however, these ossicles, which are seen in about 2–5% of the population, are completely surrounded by lamellar bone [33, 34] (Fig. 8).

Extensor Digitorum Brevis Muscle—Dorsal Anterior Calcaneus

An important calcaneal fracture is an avulsion of the origin of the extensor digitorum brevis (EDB) muscle [24, 32]. The EDB muscle is broad and thin. The lateral segments course distally to insert on the middle phalanges of the second through fourth toes, whereas the most medial segment forms the extensor hallucis brevis. The function of this muscle is to extend the first through fourth toes and the respective metatarsophalangeal joints. Forced inversion of the foot is considered the mechanism of injury so that the EDB is rapidly stretched beyond its physiologic limits resulting in a tear of the muscle along with an avulsion fracture [32]. The fracture is best depicted on the anteroposterior projection of the ankle or the frontal projection of the foot, and it characteristically appears as variably sized fragments of bone arising from the dorsolateral aspect of the anterior calcaneus (Fig. 9). Patients with this fracture present with pain and swelling in the dorsolateral midfoot that is similar to those who have an anterior calcaneal process fracture.

One pitfall is that an avulsion fracture of the attachment of the calcaneoibular ligament occasionally may appear similar on the anteroposterior ankle radiograph, but the fracture fragment appears more posteriorly located on the frontal radiograph of the foot and is usually smaller. The EDB avulsion fracture may also be mistakenly identified as an os peroneum, but the latter resides more inferiorly and is completely corticated. Occasionally, the fibular trochlea may present with a separated ossification center appearing similar to a fracture on an ankle radiograph but appearing completely corticated on a frontal foot radiograph [35].

Calcaneocuboid Ligament—Distal Anterolateral Cortex

The calcaneocuboid joint is a large lateral joint in the midfoot. A joint capsule invests the joint cavity, and it is stabilized superiorly by the calcaneocuboid limb of the bifurcate ligament, laterally by the dorsal (dorsolateral) calcaneocuboid ligament, and inferiorly by the plantar calcaneocuboid ligament and the long plantar ligament [36–38]. The structural integrity of these ligaments as well as the plantar fascia is necessary for proper function of the calcaneocuboid joint [39]. Once considered rare, avulsion fracture occurring at the calcaneocuboid joint is an important cause of persistent pain in the lateral aspect of the foot [40]. The margins of this joint should be closely inspected for fractures in patients who have an invarusion or plantar flexion injury of the foot or forced adduction injury of the forefoot. Clinically, lateral foot pain over the calcaneocuboid joint and focal soft-tissue swelling occurring proximal to the fifth metatarsal are characteristic clinical findings. Maneuvers that adduct the forefoot exacerbate pain.

Most avulsion fractures occur at the attachments of the dorsal calcaneocuboid ligament (Fig. 10). Andermahr et al. [38] classified these injuries into four types depending on the size of fracture and angulation of the calcaneocuboid joint with stress: type I, no fracture and an increased angle by 5°–10°; type 2, occasional fracture flake and angulation greater than 10°; type 3, osseous fragment greater than 5 mm and angulation greater than 10°; and type 4, compression fracture of medial cuboid and major joint distraction. Frontal and oblique foot radiographs, not ankle radiographs, are most optimal for showing these fractures, which characteristically appear as variably small linear cortical fragments that rotate when the joint distracts. MRI may be necessary to confirm the diagnosis (Fig. 11).

A potential clinical pitfall is a stress fracture of the lateral aspect of the cuboid [41]. Another clinical and radiographic pitfall may be a small avulsion fracture of the EDB insertion; however, in our experience, even small EDB fracture fragments contain more bone than just the cortex so they do not have the typical linear appearance of a calcaneocuboid ligament avulsion fracture.

Conclusion

Avulsion fractures of the calcaneus are often difficult to diagnose, but they occur in very specific locations, with characteristic radiographic appearances. A systematic evaluation of the calcaneus with attention to areas of vulnerability will assist those who interpret ankle and foot radiographs in maintaining a high diagnostic accuracy for these fractures.

References

8. Maganaris CN, Narici MV, Almekinders LC.

(Figures start on next page)
Fig. 1—Calcaneal anatomy. Diagram depicts key anatomic components of calcaneus in lateral, superior, and medial projections. FHL = flexor hallucis longus. (Drawings by Yu JS)

Fig. 2—Classification for calcaneal avulsion fractures. Type 1 is simple avulsion with variable sized bone fragment, type 2 is beak fracture with horizontal fracture extending into posterior body, type 3 is avulsion by superficial fibers of middle third of Achilles tendon, and type 4 is small beak fracture avulsed from deep fibers of tendon. (Drawings by Yu JS. Adapted with permission from Lee et al. [9])

Fig. 3—59-year-old man with type 1 calcaneal avulsion fracture who felt “pop” and acute posterior heel pain. Lateral radiograph shows superiorly displaced bone fragment (curved arrow) and donor site defect in superior aspect of calcaneal tuberosity (straight arrow).

Fig. 4—43-year-old man who fell off horse and experienced pain and bruising in back of ankle. A, Postspint radiograph obtained 2 days after injury depicts ossific fragment (arrow) in Achilles tendon approximately 5 cm above enthesis. B, Sagittal T1-weighted MR image obtained 6 weeks after injury shows thickened Achilles tendon. There is heterogeneous signal intensity within tendon and focus of low signal intensity (straight arrow) approximately 5 cm above enthesis. Defect in tubercle was similar in size to avulsed fragment (curved arrow) and likely its source.
Fig. 5—Images of medial plantar process.
A, Frontal 3D CT image of calcaneus in cadaver shows shelflike prominence of medial plantar process (arrow) where central and lateral cords of plantar fascia inserts.
B, 27-year-old male baseball player with acute heel pain after pushing off base while accelerating. Lateral radiograph shows linear break in medial plantar process (arrow).

Fig. 6—45-year-old woman who felt “ripping” sensation in bottom of her ankle 2 weeks ago.
A, Lateral radiograph shows fracture (straight arrow) through enthesophyte emanating from medial plantar process. Note saucerlike defect in inferior aspect of calcaneus from bone lysis (curved arrow).
B, Sagittal STIR MR image shows avulsion of central cord of plantar fascia with perifascicular edema (arrow) as well as bone edema surrounding bone defect.

Fig. 7—25-year-old man who fell while skiing.
A, Lateral radiograph shows linear lucency (arrow) through anterior calcaneus process corresponding to type 2 fracture.
B, Oblique view of foot affords another opportunity to identify fracture (arrow).

Fig. 8—Type 1 fracture versus os calcaneus secundarius in two patients.
A, 22-year-old man who sustained fracture during football game. Sagittal T1-weighted MR image shows small fragment of bone (straight arrow) arising from anterior calcaneus process corresponding to type 1 fracture. Portion of bifurcate ligament is shown (curved arrow).
B, 30-year-old man who did not have trauma. Oblique view of foot shows incidental ossicle (arrow) located between calcaneus, talus, navicular, and cuboid that mimics type 1 anterior process fracture. This ossicle is referred to as os “calcaneus secundarius” and is differentiated from fracture by lack of donor site in calcaneus.
Fig. 9—32-year-old female tennis player who inverted her foot and had dorsolateral bruising in foot.

A, Ankle radiograph shows rotated fragment of bone (arrow) with adjacent soft-tissue swelling that is characteristic of avulsion of attachment of extensor digitorum brevis muscle.

B, Foot radiograph shows that fragment of bone (arrow) is located in dorsal and lateral region of anterior calcaneal body.

Fig. 10—21-year-old male basketball player who inverted his foot and had pain laterally.

A, Close-up of oblique view of foot shows linear piece of bone (arrow) just proximal to calcaneocuboid joint.

B, Axial CT image shows that avulsion fracture (oval) corresponds to proximal attachment of dorsal calcaneocuboid ligament.

Fig. 11—28-year-old male hockey player with twisting injury.

A, Frontal radiograph shows swelling in lateral foot with its epicenter just proximal to base of fifth metatarsal bone (straight arrow). There is small linear bone fragment located lateral to calcaneocuboid joint (curved arrow).

B, Axial proton-density MR image shows that avulsion occurred distally at cuboid attachment manifested as gap (arrow) between ligament and cuboid. Proximal aspect of ligament can be visualized to its calcaneal attachment.