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Computed Tomography for Calcaneal Fractures: Adding Value to the Radiology Report

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ABSTRACT

Computed tomography (CT) is nowadays the cornerstone for fracture pattern delineation in calcaneal fracture, and for operative planning. It is often challenging for radiologists in generating clinically oriented and meaningful CT reports to the orthopedic surgeon. The article aims to review the commonly encountered calcaneal injuries and highlight the key points in the description of these injuries and implications of the underlying classification system with respect to the surgeon's perspective. A thorough understanding of the pathoanatomy and potential complications of calcaneal fractures also helps radiologists in tailoring the radiology report in contribution to overall patient's management and prognostication. By doing so, we suggest ways in which the radiologists can add value to the radiology report.

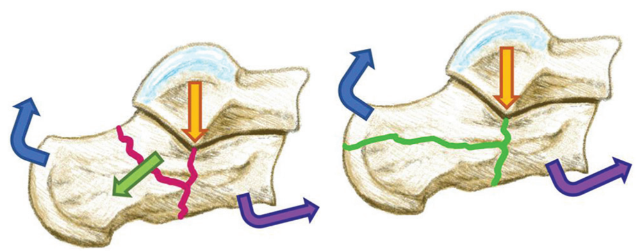
Keywords: Calcaneal fractures, Computed tomography, Report

OVERVIEW OF CALCANEAL FRACTURES

The calcaneus is the largest tarsal bone and most commonly injured tarsal bones that account for 2% of all fractures.[1] It is the most inferior bone in the body that constantly supports the axial load from the weight of the body. It is an uncommon fracture that could cause significant patient morbidity due to its role in gait, axial load transmission, and foot motion. In general, calcaneal fractures are divided into extra- or intra-articular fractures, depending on the involvement of the posterior facet which carries the majority of axial load during weight-bearing. Extra-articular fractures (accounting for 25% of fractures) do not involve the posterior facet, while the intra-articular fractures (accounting for 75% of fractures) involve the posterior facet. The more common intra-articular fractures involve axial loading mechanisms (e.g. falling from height). Modern evaluation of calcaneal fractures heavily relies on CT with multiplanar reformats with the use of volume rendering reconstruction allowing better characterization of fracture lines, displacement of bone fragments, and visualization of subtalar joint involvement. CT also allows better visualization of the surrounding soft tissues compared to radiography and may show tendon entrapment or dislocation. All of these are important in deciding further management and affect patients' prognosis.[1]

CLASSIFICATION SYSTEMS FOR INTRA-ARTICULAR FRACTURES

For intra-articular fractures, the two most commonly used classification systems for calcaneal fractures are the Essex-Lopresti classification and Sanders classification. The Essex-Lopresti classification system was developed in 1952. It is primarily based on radiographic findings and distinguishes intra-articular fracture patterns into two types (depending on the exit point of the secondary fracture line): "tongue type" and "joint depression" fractures[2] [Figure 1]. Tongue-type fractures can be distinguished from joint depression type by the involvement of the posterior tuberosity.[1,3] The limited popularity of the classification system is due to its limited prognostic relevance. On the other hand, the Sanders classification, which was developed in 1993, is currently the most widely used system[4] [Table 1 and Figure 2]. It is primarily based on CT coronal oblique image with the plane perpendicular to the posterior subtalar joint and depends on the number of fractures and the fracture line position at the posterior calcaneal facet. It is not only helpful in pre-operative planning but also of significant prognostication value. It correlates with the clinical outcome with little interobserver variability.[1] In general, the prognosis worsens with the increase of articular comminution, for example, type III fractures were four times more likely to require subtalar arthrodesis than type II fractures.[5] In addition, the surgical reconstruction becomes more difficult not only with the comminution but with the translation of the fracture lines closer to the medial wall.[6] The most commonly used and optimal surgical approach is the lateral approach. Fractures that require medial/combined approaches or lead to more difficulty with reduction will increase intraoperative time and are less likely to result in surgical success.[3,7,8] The flat nature of the lateral calcaneal wall allows easier surgical access and direct visualization of intra-articular fractures, but is associated with higher wound and infectious complications. The medial wall of the calcaneus is associated closely with the posterior tibial neurovascular bundle and its branches making the surgical approach challenging.[3,8]



The primary fracture line is due to axial loading acting onto the angle of Gissane (yellow arrow). The secondary fracture line determines the fracture pattern further. A posteriorly directed force (green arrow) creates the joint depression type fracture, while axially directed force creates tongue type fracture. Direction of displacement of bone fragments are indicated by blue and purple arrows.

Figure 1: Essex-Lopresti Classification.[2]

Table 1: Key points for calcaneal fracture CT reporting.

What does the surgeon want to know?	
Classification	1. Number of fracture lines through subtalar joint (Sanders classification) 2. Essex-Lopresti type (tongue type vs joint depression type)
Fracture pattern	1. Severity of comminution and displacement (step-off) at the subtalar joint. 2. Whether the sustentacular (constant) fragment is large in size for 'anchoring' lateral fragments. 3. Involvement of calcaneocuboid joint if any, and extent (more or less than 25%).
Signs suggesting potential soft tissue injuries	1. Any significant calcaneal widening ("blowout" with loss of subfibular space (leading to entrapment or displacement of peroneal tendons, sural nerve and fibulocalcaneal impingement) 2. The presence of lateral malleolar fleck sign (suggesting peroneal instability), peroneal tendon entrapment.
Deformity	1. Any significant flattening of the of the calcaneus, with loss of Bohler's angles 2. Any varus or valgus deformity of the calcaneal tuberosity.

WHAT SURGEONS WANT TO KNOW FOR INTRA-ARTICULAR FRACTURES

Sanders classification divided intra-articular fractures of the calcaneus into four types based on the fracture line location at the posterior facet.[4] Nondisplaced fractures (displacement <2 mm) are classified as type I irrespective of the number of fracture lines. Types II–IV are displaced fractures with an increasing number of fracture lines and fragments, depending on the position of the hindfoot and the amount of force during stress.[1] Fracture lines are described as A through C, with A representing lateral fracture lines, B representing fracture lines through the middle of the posterior facet, and C representing medial fracture lines adjacent to the sustentaculum tali [Figure 3].

The mechanism of underlying fractures helps us in understanding the possible sequelae and findings that are important from surgeons' perspective [Table 1]. Excessive axial loading on the Gissane angle (formed by the posterior facet and superior calcaneal body) causes a primary fracture occurring in the sagittal plane and runs through the posterior facet, dividing it into anteromedial and posterolateral fragments.[3,9] The fracture line may extend anteriorly to involve the cuboid facet.[7] The anteromedial fragment (containing the sustentaculum tali) is described as the constant fragment, as it is fixed firmly to the talus by the deltoid and interosseous talocalcaneal ligaments. The posterolateral fragment is dislocated laterally and impacted

Types	Description
I	Non-displaced fractures (displacement <2 mm) with any number of fracture lines.
II	Two part fracture with one fracture line and is divided into three subtypes based on the side of the fracture line in relation to the posterior facet and the subtalar joint: lateral (IIA), central (IIB), or medial (IIC).
III	Three part fractures from two lines of fracture, divided into subtypes IIIAB (with two primary lines, one lateral and one central relative to the posterior facet and subtalar joint), IIIAC (two primary fracture lines, one lateral and one medial relative to the posterior facet and subtalar joint), IIIBC (two primary fracture lines, one central and one medial relative to the posterior facet and subtalar joint).
IV	Four part or more than three lines of fracture

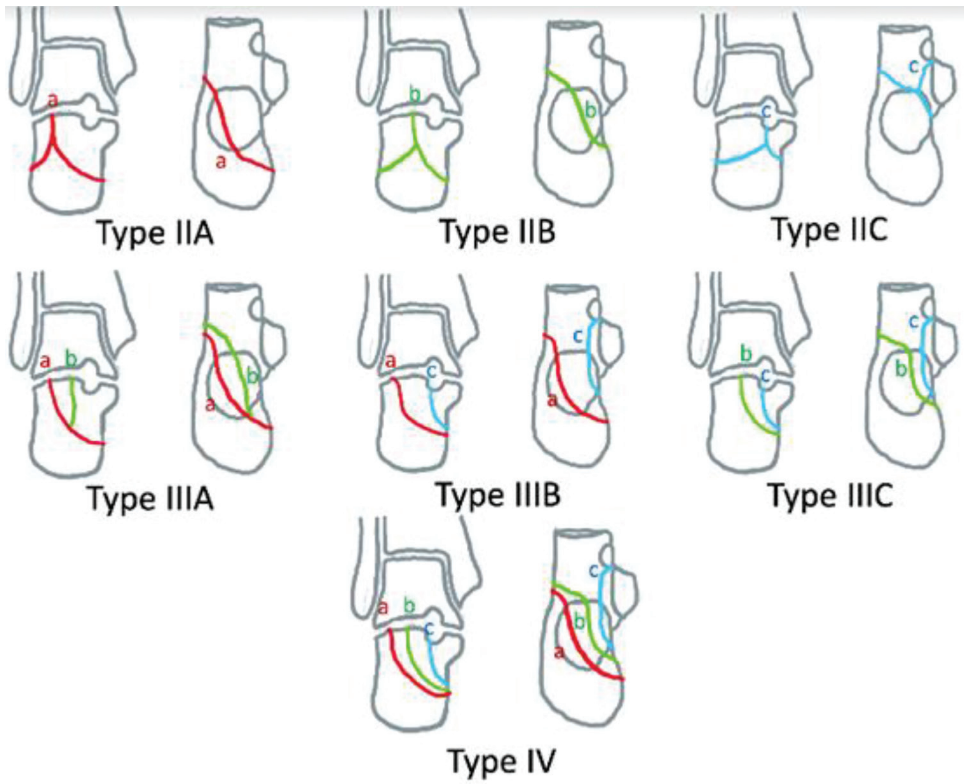


Figure 2: Sanders Classification.[4]

into underlying weakest cancellous portion of the calcaneus, leading to a "step off" in the posterior facet and lateral displacement of the bone fragment into the fibula causing impingement to the soft tissues in that area.[1] There might be multiple secondary fracture lines may develop resulting in different patterns, including joint depression or tongue-type fracture [Figure 4].

Severity of comminution and displacement (step-off) at the subtalar joint and whether the sustentacular (constant) fragment is large in size for "anchoring" lateral fragments are important aspects for pre-operative planning.

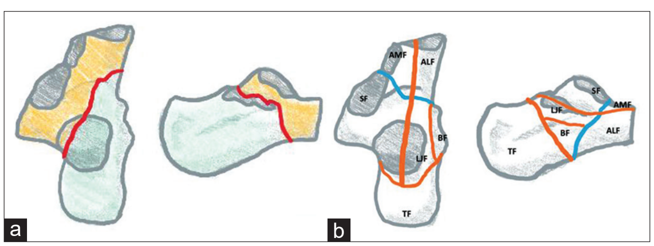
For tongue-type fractures, there is a risk of posterosuperior displacement of the tuberosity from tension pulling from the Achilles tendon. As a result, these fractures may lead to skin tenting, with a reported rate of posterior skin compromise of 21%.[10] The posterior heel is at risk of subsequent pressure necrosis due to compromised blood supply, and thus requires urgent surgical management.[3,8,11] Underlying smoking history and comorbidity (such as diabetes mellitus or peripheral vascular disease) may also worsen this condition and wound healing post-operatively.

Therefore, concomitant soft tissue injuries should never be overlooked from both radiologists' and surgeons' point-of-view. These also affect the surgical decision-making (such as open versus minimally invasive approach) as open surgery may potentially cause higher rates of wound and infectious complications and directly affect patients' outcome.[1] Some authors even advocate postponing surgery until the wound demonstrates signs that portend good wound healing.[8]

Knowing the anatomy of the calcaneus would help us look for potential soft tissue structures that could be injured. Medially,

Different types of intra-articular fractures: Sanders type I fracture (non-displaced) (a) Sagittal and coronal CT of the calcaneus showed the intra-articular fracture with primary fracture line across the posterior facet with minimal displacement (<2mm). Sanders type IIA fracture (b) Coronal and sagittal CT reformat images showed the primary fracture line across lateral aspect posterior facet separating calcaneus into two major parts with significant (>2 mm) displacement. Sanders type IIC fracture (c) Coronal and sagittal CT reformat images showed primary fracture line across medial aspect posterior facet into two major parts, with step-off of lateral fragment (joint-depression type). Sanders type IIIAB fracture (d) Coronal and sagittal CT reformat images showed comminuted fracture at posterior facet with one lateral and one central relative to the posterior facet and subtalar joint. Sanders type IV fracture (e) Coronal and sagittal CT reformat images showed comminuted fracture at posterior facet with more than four major fragments

Figure 3: Examples of intra-articular calcaneal fractures.



The primary fracture line from axial loading mechanism runs obliquely through the calcaneus across the posterior facet, producing anteromedial and posterolateral fragments (a). The anteromedial fragment contains the anterior and middle facets, sustentaculum, and residual posterior facet. The posterolateral fragment contains the tuberosity and lateral wall.

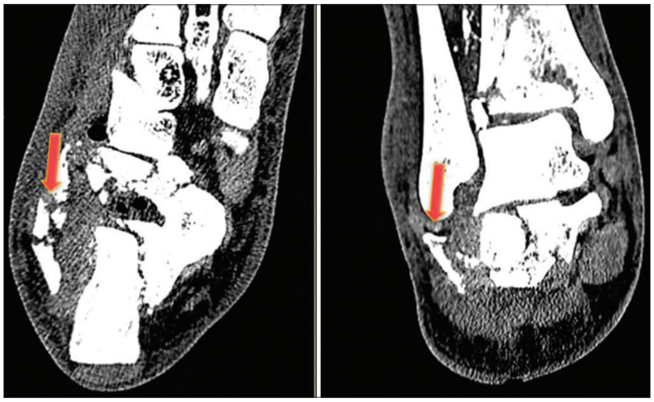
The secondary fracture line can separate anterior process into anteromedial fragment (AMF) and anterolateral fragment (ALF), or extend medially, separating the sustentacular fragment (SF) from the anteromedial fragment. It can also divide posterolateral segment into the lateral joint fragment (LJF), blowout fragment (BF), and tuberosity fragment (TF) (b).

Figure 4: Calcaneal fracture lines for intra-articular fractures.

there is a groove for flexor hallucis longus tendon inferior to the sustentaculum tali. Laterally, there is a tuberosity called peroneal tubercle, beneath which the peroneus longus tendon passes through.

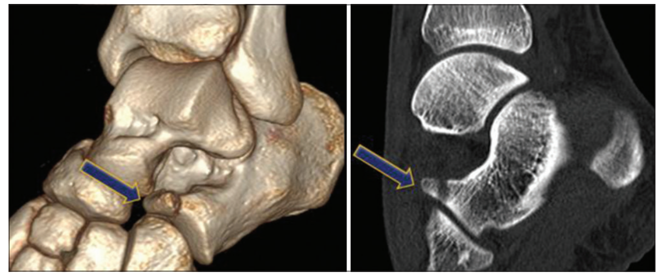
Other soft tissue structures passing through the lateral aspect of calcaneus maybe injured by the same injury mechanism, therefore radiologists should pay attention to any significant calcaneal widening or any lateral wall blow out on CT,[1,7] which lead to loss of subfibular space and potential entrapment or displacement of peroneal tendons [Figure 5], sural nerve and fibulocalcaneal impingement. Entrapment presents an obstacle to reduction of a fracture, therefore imaging of entrapment is of paramount importance.[12]

Avulsion of the superficial peroneal retinaculum from the distal fibula can cause peroneal tendons dislocation.[3,13] Commenting on the presence of lateral malleolar fleck sign, due to underlying superficial peroneal retinaculum tear, would be very important as it suggests underlying peroneal instability. The prevalence of peroneal instability has been



Coronal CT reformat image showed the presence of comminuted intra-articular calcaneal fractures with lateral blow-out fragments causing subfibular narrowing and peroneal tendon entrapment (arrows)

Figure 5: Peroneal tendon entrapment.



3D reformat and CT sagittal reformat images showed extra-articular fracture at anterior process of calcaneus (arrows) involving >25% of articular surface on sagittal image, which requires internal fixation.

Figure 6: Fracture anterior process of calcaneus.

shown to be increased with increasing severity of calcaneal fractures as shown on Sanders' grading.[14]

It is important to comment on calcaneocuboid joint involvement and the extent of involvement (i.e. more than or <25%), due to potential complications of subtalar and calcaneocuboid arthritis. It has been shown that there is a significant correlation between Sanders classification and calcaneocuboid joint involvement. The higher the Sanders types, the more likely it is to involve the calcaneocuboid joint, with a reported rate upto 55% for Sanders IV fractures.[15]

Any significant flattening of the calcaneus, with loss of Bohler's angles. Bohler's angle <20° are indicative of posterior facet collapse.[3] Any varus or valgus deformity of the calcaneal tuberosity should also be commented for pre-operative planning.

Last but not least, it is the radiologist's role to look for contralateral calcaneus involvement (10%), associated thoracolumbar spinal fractures (10%) and tibia plateau, and plafond fractures,[3,7] knowing they share common axial loading mechanisms of injury. There is also possible associated other foot injuries and talar neck fracture (10%).[3]

EXTRA-ARTICULAR FRACTURES

Extra-articular fractures are classified by the anatomical division of the heel in three parts.[9] Type A fractures involve the anterior process of the calcaneus. Fractures that involve the mid calcaneus or body, including the trochlear process, sustentaculum tali, and lateral process, are type B fractures. Type C extra-articular calcaneal fractures involve the posterior calcaneus, including the posterior tuberosity and the medial tubercle [Figure 7]. They result from lower energy forces and hence carry a better prognosis. Injuries are typically isolated and result from twisting or lower impact axial loading forces.[7]

IMPLICATIONS OF FRACTURE PATTERNS ON MANAGEMENT

Surgical goals aim at anatomical and functional restoration, which include reducing joint incongruencies, removal of impinging fragments, restoring heel morphology, and re-establishing ligamentous/tendinous stability, in the absence of infection.[3,7] Surgical approaches can be divided broadly into extensile lateral approach (ELS), which is the most commonly used one, medial approach, or other minimally invasive surgeries.[3,8]

ELS is the workhorse operative approach for most displaced intra-articular calcaneal fractures, where access to the posterior facet, posterolateral, anterolateral fragment, and subtalar joint is required.[3,8] Medial approach gains good access to the sustentaculum tali, inferior and medial aspect of the calcaneus. It serves as the approach of choice for open calcaneal fractures as it is where the sustentaculum tali exits through the skin. However, due care is required to protect the neurovascular structures nearby, particularly the medial calcaneal nerve, and the tibialis posterior tendon. Besides, direct visualization of the subtalar joint is not provided with this approach.[3,8] Minimally invasive surgeries (e.g. limited-incision sinus tarsi approach, percutaneous fixation, and arthroscopic-assisted fracture reduction) aim to reduce wound and infectious complications. These newer approaches have lowered complication rates and maintained comparable clinical and radiologic outcomes.[8]

In general, intra-articular fractures require open reduction and internal fixation (ORIF) in the majority of cases as subtalar articular stepping is never fully reduced by closed reduction methods. Exceptions exist where non-displaced (Sanders I) intra-articular fractures are generally treated with conservative means, which include ankle splint and non-weight bearing for a minimum of 4–6 weeks.[3] Severely comminuted (Sanders IV) intra-articular fractures require combined ORIF and subtalar joint arthrodesis.

Coronal and sagittal reformat CT of the calcaneus showed posterior calcaneal extra-articular fracture (type C) with moderate displacement and mild comminution

Figure 7: Extra-articular calcaneal fracture.

Extra-articular fractures are in general treated conservatively. Exceptions exist when there is significant displacement of sustentaculum tali (>2 mm), fracture through posterior tuberosity destabilizing Achilles tendon,[7] anterior process fracture involving >25% articular surface[16] [Figure 6], or significant comminution of calcaneal body.

On top of these, the patient's age, comorbidity, and concomitant injuries also affect the choice of management, which is discussed on a case-to-case basis.

Urgent surgical indications include any open fracture or fracture pattern that places the soft tissue envelope at risk for necrosis, like the tongue-type fracture.[3,8]

COMPLICATIONS

Understanding the pathoanatomy of calcaneal fractures would be easy for radiologists to perform direct search for particular complications and alert the surgeons. In general, complications associated with calcaneal fractures include compartment syndrome, fracture blisters, skin tenting with wound necrosis, sural nerve pathology, tarsal tunnel syndrome, peroneal tendon subluxation, subtalar and calcaneocuboid arthritis, and malunion.[8]

CONCLUSION

CT forms a standard step in the diagnosis and workup of intra-articular calcaneal fractures, which provides important information for planning of operative fixation and prognostication. Radiologists should familiarize themselves with key details of the interest of surgeons and convey them in CT reports in aiding decisions of patients' management.

Contributors

HM KWOK and NY PAN contributed to the concept or design, acquisition of data, analysis or interpretation of data, drafting of the manuscript, and critical revision for important intellectual content. All authors had full access to the data, contributed to the study, approved the final version for publication, and take responsibility for its accuracy and integrity.

Ethics approval

This study was conducted in accordance with the Declaration of Helsinki. The need of consent is waived by the local ethics board.

Reference number for ethical board

KW/EX-21-085(160-01).

Declaration of patient consent

Institutional Review Board (IRB) permission obtained for the study.

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Conflicts of interest

There are no conflicts of interest.

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