Figure (1): A photograph of a sectioned calcaneus shows bone trabeculae diverging anteriorly (1) and posteriorly (2) from a point at the middle of sinus tarsi (S) enclosing the pseudocystic triangle (P.S) in between. Other trabeculae (3) passing from anteromedial talar facet inwards. The fourth seen parallel to the middle of posterior surface of calcaneus.[1]

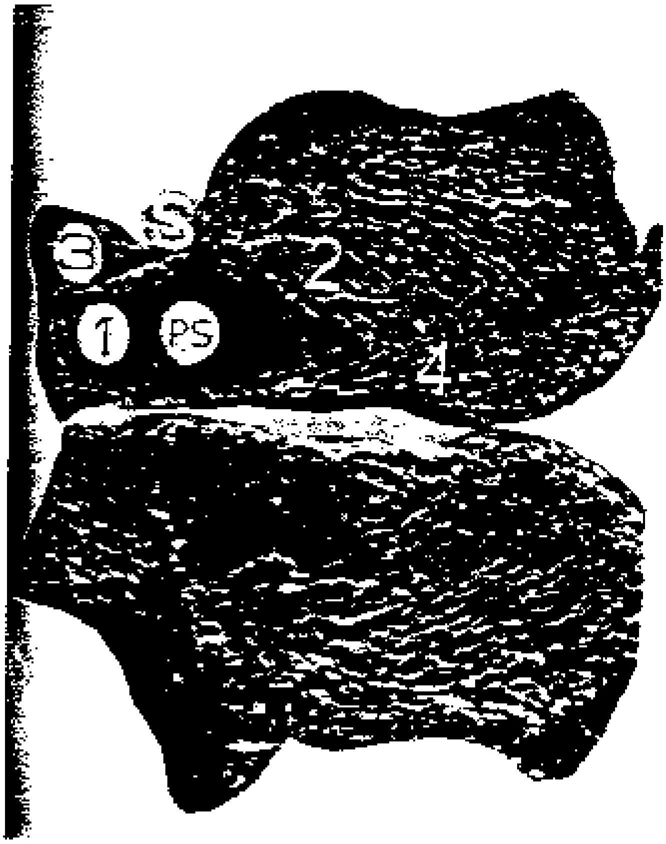
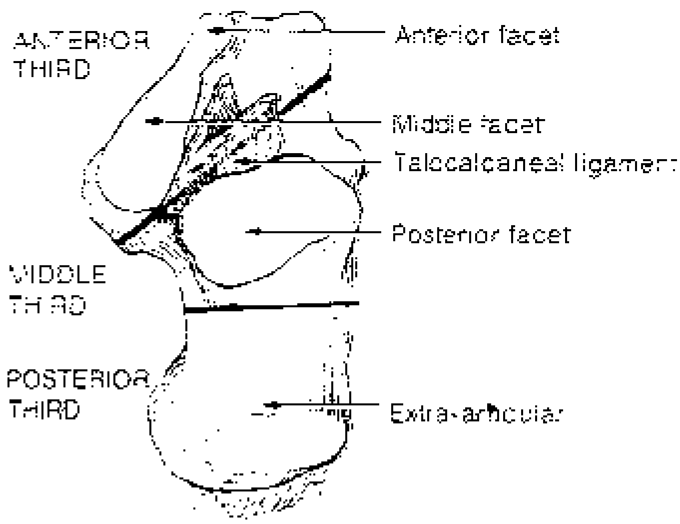


Figure (2): Superior surface of calcaneus is divided into thirds. The posterior one is extra-articular, the middle one contains the posterior facet and the anterior one contains the articular surface of middle and anterior facets.[4]



The interosseous talocalcanean ligament inserts in the floor of the tarsal canal and serves to separate the posterior facet from others.(2,3,5) Although the anterior, middle and posterior talocalcaneal articular facets have a separate synovial cavities and are curved in opposite directions, they function as a single reciprocal unit.(10,13)

The triangular inferior surface of the calcaneus expresses two tuberosities.(4,12,13) The medial tuberosity is the main weight-bearing structure and gives origin to the abductor hallucis muscle and the lateral tuberosity which gives origin to the abductor digiti minimi.

The medial calcanean surface has the sustentaculum tali, whose superior surface carries the middle articular facet and its inferior surface is grooved by the flexor hallucis longus.(4,12) The triangular posterior surface of the calcaneus is convex and gives insertion to the Achilles tendon.(4) The anterior surface of the calcaneus is entirely articular and shares in the articulation with the cuboid.(4,10,12,13)

The subtalar joint:

The anterior and posterior talocalcanean joints form a single functional unit; called the subtalar joint.(13)

a-The posterior talocalcanean joint: The convex posterior calcanean facet articulates with the concave talar one and connected by fibrous capsule and interosseous ligaments. The capsule is lined with synovial membrane, and the joint cavity does not communicate with other tarsal joints.(13)

b-The talo-calcaneo-navicular joint: It is a restricted ball and socket joint. The rounded head of the talus is received into the concavity formed by the posterior surface of the navicular, the middle and anterior calcanean facets and the upper surface of the spring ligament.[13]

The subtalar joint has a remarkable degree of stability resulting from the accurately fitting articular facets and the ligaments stretching between them.[10,13]

The tarsal canal is occupied by strong flat anterior and posterior interosseous ligaments, whose fibers diverge upward in relation to each other in a "V" shaped manner. Its plane is perpendicular to the axis of motion of subtalar joint. Since the greater part of the ligament is lateral to the axis of subtalar movement it becomes tense with inversion and relax with eversion.[10]

Anatomy of the lateral compartment of the hind foot :

The calcaneus exposes some visible and palpable bony prominences that can be used for morphological orientation and surgical exposures. Its tuberosity is easily identifiable as the Achilles tendon insertion is located on the postero-inferior two thirds of the tuberosity. Its supero-lateral corner is easily palpated, unlike the infero-lateral border.[13-15]

The lateral malleolus is subcutaneous and marks the proximal margin of the subtalar joint. The anteroinferior depression in relation to the lateral malleolus is the sinus tarsi, which outlines the lateral end of the subtalar joint.[14]

The lateral surface of the body of the calcaneus is flat and contains a shallow groove for the peroneal tendons passing postero-inferior to the fibula[4,12] (Fig. 3). There may be a separate groove for the peroneus longus tendon.[15,16] The peroneus brevis tendon runs antero-superior to the peroneus longus tendon to its insertion at the fifth metatarsal base. Both tendons course over the calcaneofibular ligament within their own sheath. The later is attached to the peroneal tubercle and divided by the peroneal trochlea.[14]

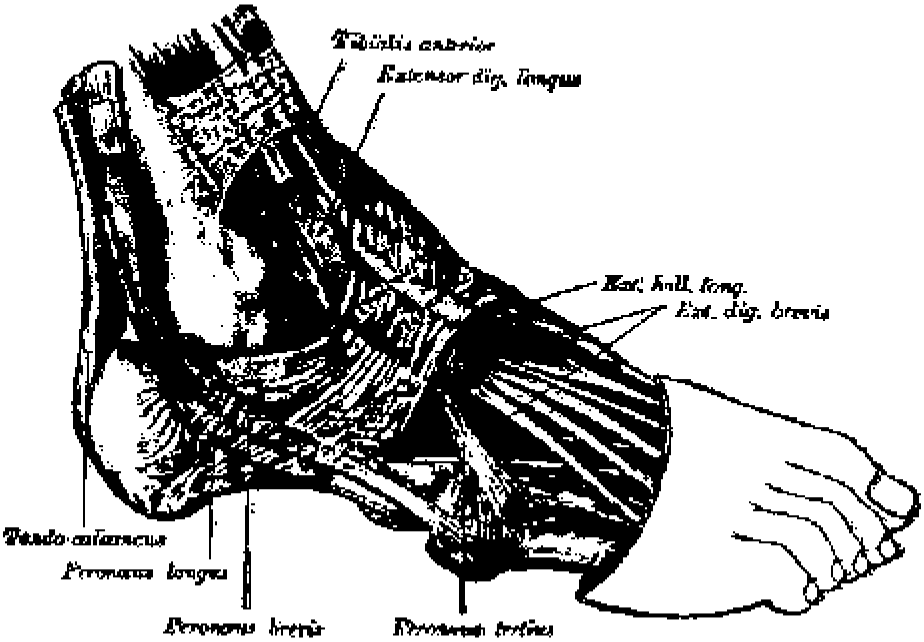


Figure (3): Lateral view of the calcaneus showing the peroneal tendons passing postero-inferior to the fibula.[12]

The calcaneofibular ligament is a rounded cord like band which is intimately attached to the capsule of subtalar joint and to the peroneal tendon sheath on its medial surface (Fig. 3).[16] Both ligament and sheath may be disrupted as the lateral wall is crushed during fracture of the cacaneus.[14,15]

The lateral calcanean surface has a relation to the sural nerve as it descends posterior to the peroneal tendons.[15] Its most constant site is ten cm above the tip of the lateral malleolus just at the lateral border of the Achilles tendon and superficial to the deep fascia. It passes one cm postero-laterally behind the lateral malleolus from which it is separated by the peroneal tendons and divides at the level of the tuberosity of the fifth metatarsal into two terminal branches, the lateral and medial. It supplies the skin over the postero lateral part of the leg, the dorso-lateral surface of the foot and the lateral side of the little toe.[13,14]

The skin over the posterolateral aspect of the heel is supplied by the posterior peroneal artery which is the continuation of the peroneal artery after it supplies the perforating, the communicating and the antero lateral malleolar branches.[17]The calcaneus is supplied by nutrient branches from the peroneal and posterior tibial arteries.[17]

PHYSIOLOGY OF THE SUBTALAR JOINT

From the functional point of view, the subtalar joint is a single axis joint which behaves like an oblique hinge.[13,18] The talo-calcaneo-navicular joint has 40°(± 7°) range of motion, with an axis of rotation, that passes dorsomedial through the navicular and the plantar lateral aspect of the calcaneus (Fig 4).[5] Motion about this axis is best described as inversion and eversion from the neutral position.[5] When the capacity of inversion and eversion of the subtalar joint is added to ankle motion, a universal joint configuration is approximated.[18]

At a heel strike on uneven ground the subtalar joint can accommodate the talus to be aligned correctly in the mortise, facilitating free ankle motion. Similarly, if the heel contacts the ground off center, either medially or laterally, the subtalar can accommodate this offset and allow normal ankle motion and then normal progression of gait.[5,18] Loss of this accommodative (shock absorber) function of the subtalar joint causes the talus to bind in the ankle mortise, increasing shear stress and decreasing efficiency of the gait propulsion.[5,18]

The heel pad also plays an important role in absorbing the shock of heel strike and helping to accommodate ankle motion.[14,15]

Another important biomechanical consideration is the relationship between alignment of the subtalar and the midtarsal joints. Normally the mid tarsal joint allows a small amount of motion in both sagittal and frontal planes. The degree of motion that can occur is determined to a large extent by the relative alignment of calcaneus and talus. When the calcaneus is everted, the axes of the talo-navicular and calcaneo-cuboid joints are parallel and motion can occur at the mid tarsal joint. With the heel in inversion, the axes of the two joints are no longer parallel and motion at the mid tarsal joint is markedly blocked (Fig 5). This interrelationship improves the efficiency of gait; at a heel strike the subtalar joint everts, "unlocking" the midtarsal joint and creating a flexible midfoot to allow further accommodation of the foot to the ground and better absorption of the energy of impact.[5, 19] At push off, the subtalar joint is inverted, "locking" the midtarsal joint to create a rigid lever at the mid-foot to gain a mechanical advantage for forward propulsion.[5,18]

Between heel strike and push-off, the ankle joint dorsiflexes, allowing the body to move forward and as this forward motion occurs, weight is transferred from heel to toes.[5,18]

During normal walking the vertical load applied to the foot is roughly equal to the body weight, while during running the vertical load increases to reach two and half times body weight.[5]

To summarize, the foot serves as a flexible shock absorber during heel strike, converts to a relatively stable lever arm during push-off, provides a stable basis of support during stance and generally facilitates ambulation and propulsion.[5, 18]

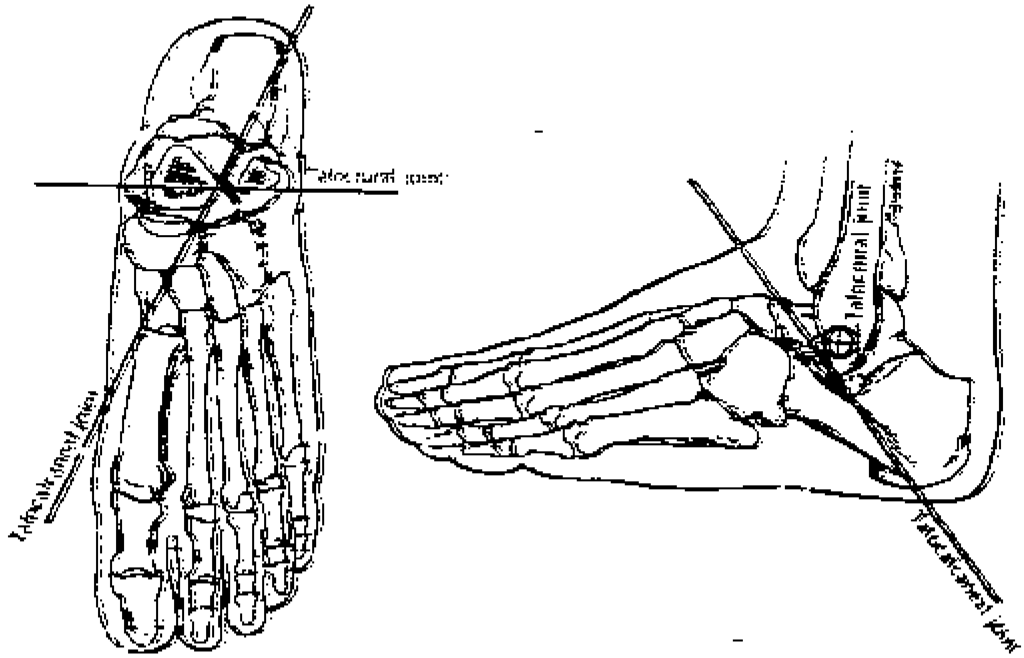


Figure (4): The axes of rotation of the talocrural (ankle) and talocalcanean (subtalar) joints as seen in the dorsoplantar and lateral projections.[5]

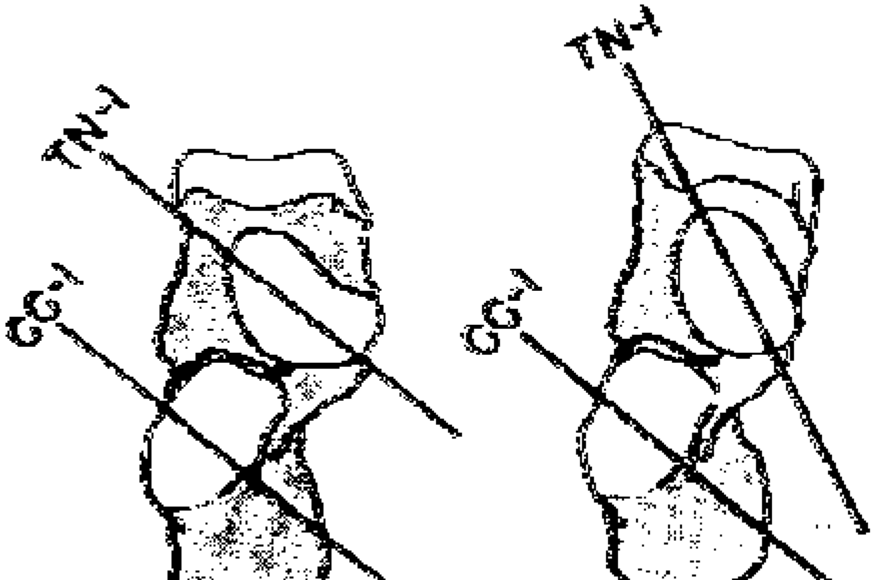


Figure (5): Eversion of the heel (left) results in parallelism of the axes of motion of the calcaneocuboid (CC-I) and talonavicular (TN-I) Joints for facilitation of motion, whereas inversion (right) produces divergence of these axes and restricts motion at the midtarsal joint loading.[5]

FRACTURES OF THE CALCANEUS

The worst outcome of calcanean fractures follow those in which the bone has been severely crushed with intra-articular extensions, markedly broadened with lost tuber joint angle and subtalar joint derangement.[6,18, 19]

Classifications: Fractures of the calcaneus may be intra-articular or extra-articular. The later is less common, forming about 25% of all calcanean fractures.[5, 15]

(1) Essex-Lopresti classification (according to the subtalar joint involvement):[20] (figure 6,7)

(2) Rowe classification (according to joint affection):[20] (figure 8)

(3) Crosby and fitzgibbons (according to CT scan):[21]

Type I: Small non-displaced fracture fragment.

Type II: Displaced fracture.

Type III: Comminuted fracture.

(4) Sander's classification (According to CTS picture):[22] (Fig. 9)

Type I: Non-displaced.

Type II: Two parts (split).

Type III: Three parts (split depression).

Type IV :Comminuted.

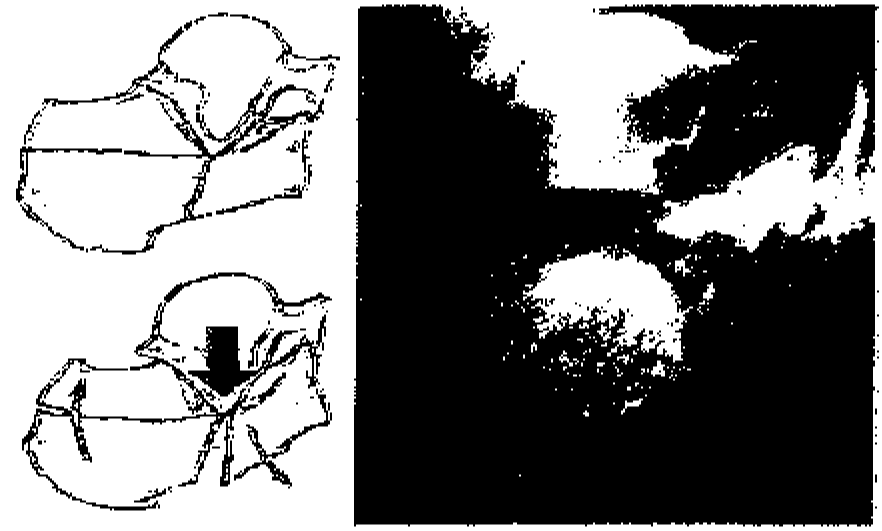


Figure (6): Essex-Lopresti tongue-type fracture. Vertical loading of calcaneus by lateral process of talus produces primary fracture line from crucial angle of Gissane to plantar calcanean surface. Secondary fracture line runs back to exit at posterior border of calcanean tuberosity. With Further progression of force, anterior end of tongue is depressed inside lateral wall of body, and tuberosity is displaced proximally.(4)

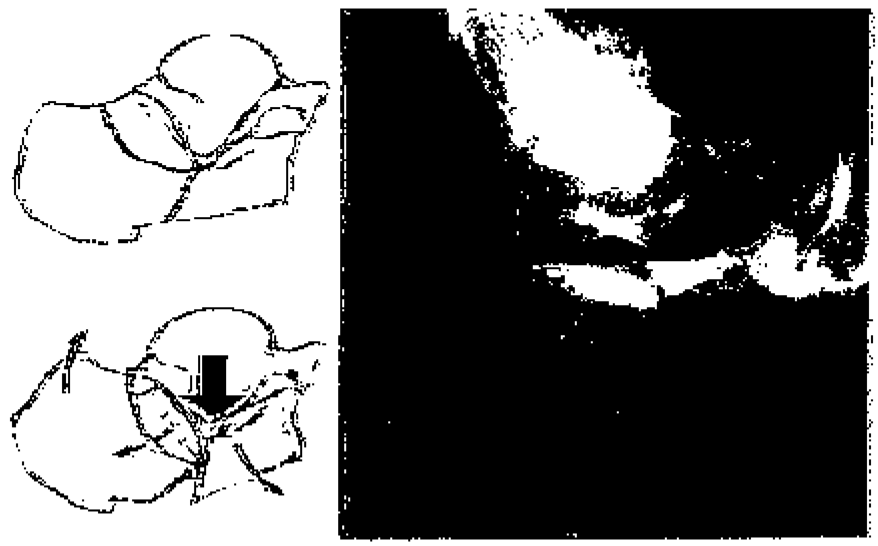


Figure (7): Essex-Lopresti joint depression type fracture. Vertical loading by lateral process of talus produces primary fracture line from crucial angle of Gissane to plantar calcanean surface. Secondary fracture line runs across calcanean body to exit just behind posterior facet. With further progression of force, lateral one half joint fragment is depressed into spongy bone of calcaneus inside lateral wall. Primary fracture line opens up, displacing tuberosity proximally with loss of tuberosity joint angle.(4)

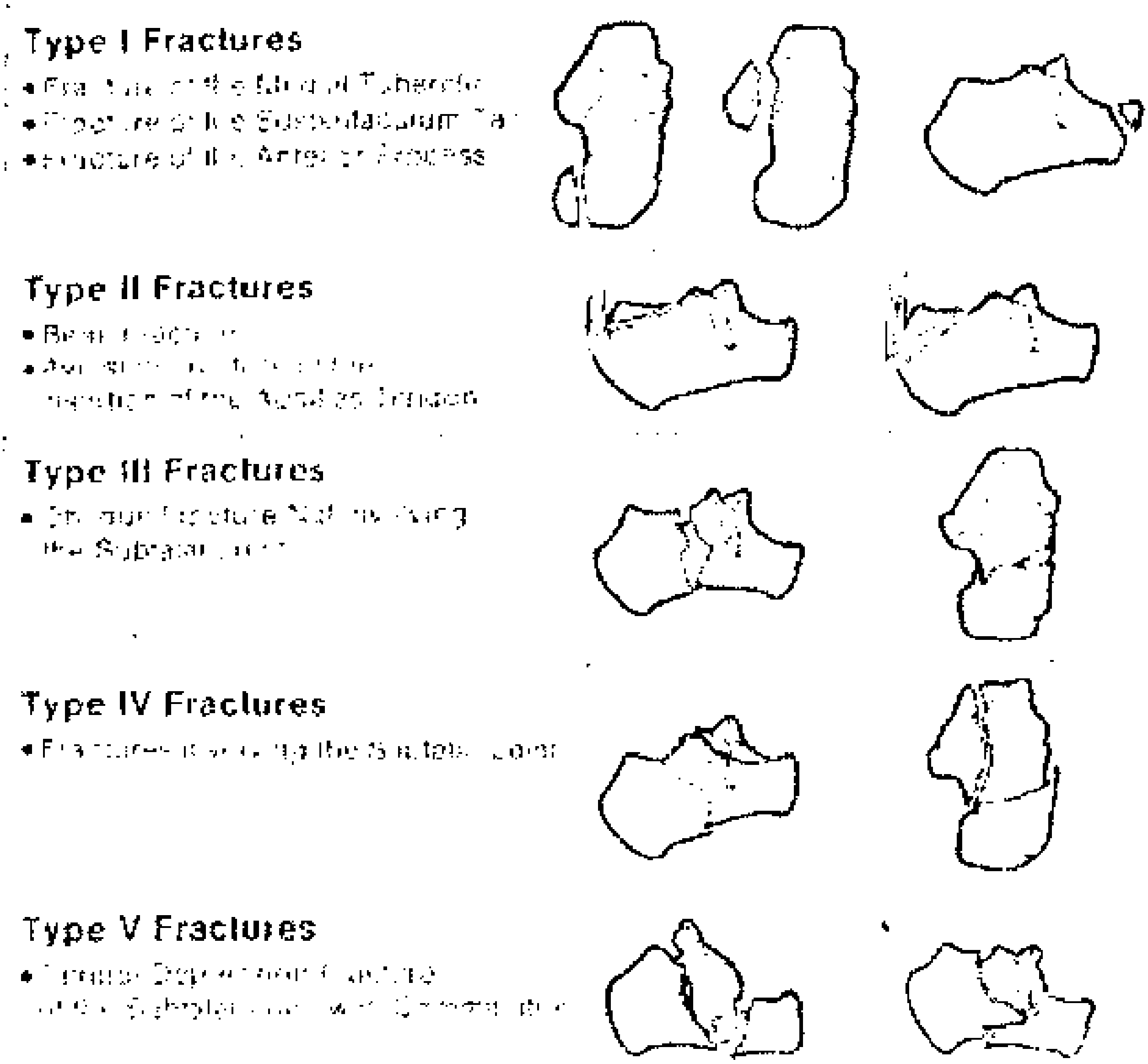


Figure (8) : Rowe classification of calcanean fractures according to joint affection.[20]

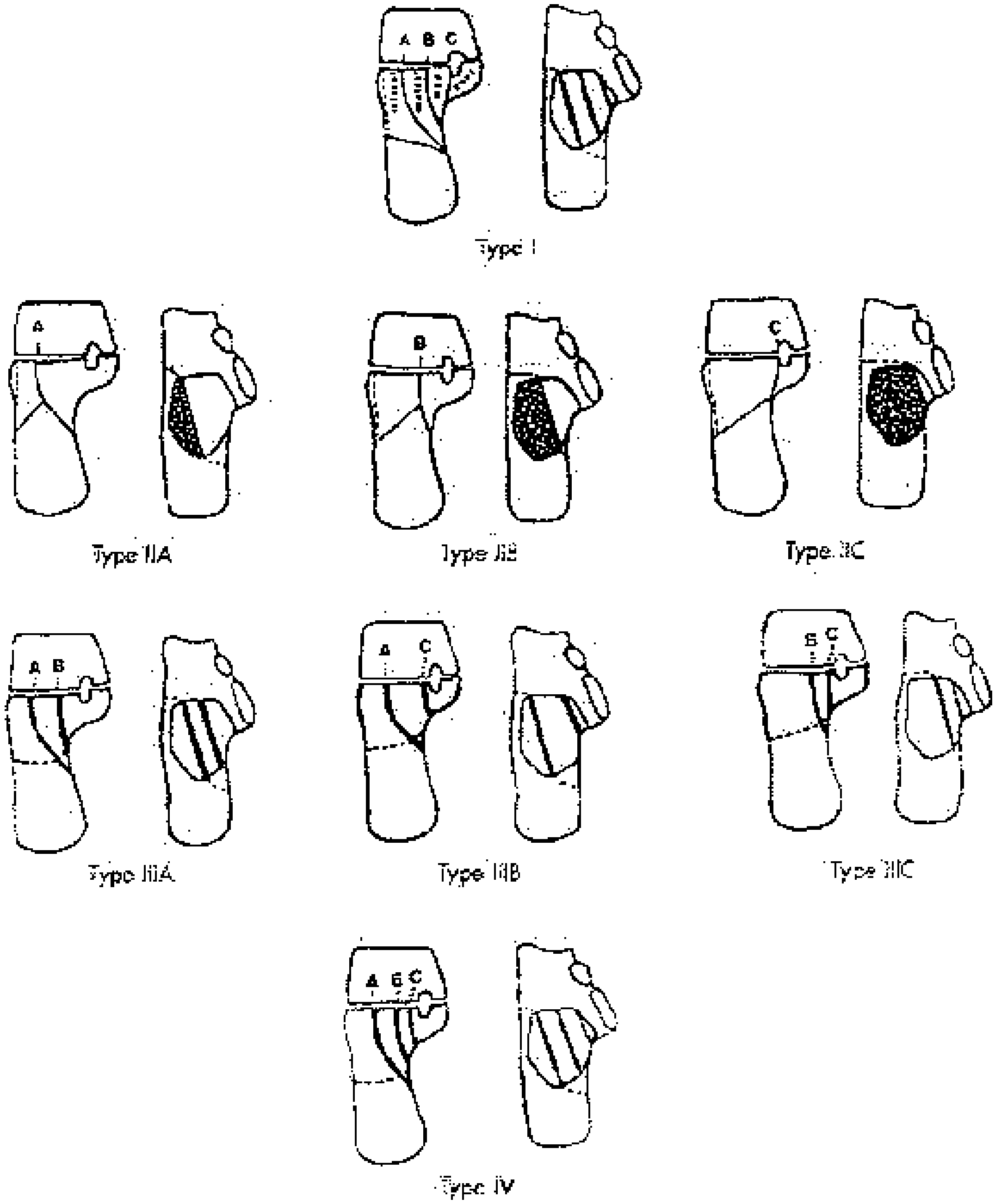


Figure (9): Classification of intra-articular fractures of the calcaneus as seen on coronal CT scans of the subtalar joint, (Sander's Classification).[5, 22]

MECHANISM OF INJURY

1. **Axial loading :** is responsible for the majority of intra-articular fractures and usually results from a fall from a height.[23]

The calcaneus initially fractures into two main fragments, with the primary fracture line running into the posterior facet of the subtalar joint. The anteromedial (sustentacular) fragment is rarely comminuted and remains attached to the talus by the deltoid and interosseus ligaments. The posterolateral (tuberosity) fragment displaces supero-laterally, resulting in incongruity of the posterior facet, widening and shortening of the heel.[20](Fig.6)

When sufficient force is applied to the heel , comminution of the tuberosity fragment occurs and secondary fracture lines develop. Essex-Lopresti, identified two commonly occurring patterns; the tongue type and joint depression type.[20](Fig.6,7)

2. **Twisting forces:** These may cause many of extra-articular fractures, particularly those of the anterior process and the sustentaculum tali.[5]

3. **Avulsive muscle forces:** the calcanean tuberosity may be avulsed by the triceps surae.[5]

4. **Direct blows:** Usually it causes open fracture with extensive soft tissue damage.[5]

DIAGNOSIS OF CALCANEAN FRACTURES

CLINICALLY: The most common symptom in recent fractures is moderate to severe pain. In addition, the patient is unable to bear weight and there is rapid swelling around the heel.[15]

Objectively, there is severe tenderness, swelling , ecchymosis and blistering of the skin. The heel is distorted with widening and shortening. Associated injuries, especially fracture of lumbar spine (30%) and lower extremity injuries (70%) should be excluded.[2-5]

In malunited calcanean fractures, the patient complains of disfigurement of the affected heel with disabling pain on standing or walking for short distances. Pain on the lateral side of the heel may originate from lateral impingement of soft tissue structures by the extruded lateral calcanean wall. Circumferential pain at the level of sinus tarsi may be due to post-traumatic subtalar arthritis due to malunion of intra-articular fractures. Both types of pain can be differentiated by anaesthetic blocking of subtalar joint.[6-9]

Mal-alignment of hindfoot may appear in varus or valgus.[6-9]

RADIOLOGICALLY:[24]

(1) Anteroposterior view of the foot and ankle: demonstrates the extension of the fracture into the calcaneocuboid joint with or without medial subluxation of the talus at the talonavicular joint.[4, 21]

Antero-posterior view of the ankle usually shows the extent of broadening of the heel especially on the lateral side. This can be evaluated by measuring the calcaneo-fibular space. If the space is occupied by calcanean bony tissue touching the lateral malleolus, this indicates disruption of the lateral calcanean wall with broadening of the heel.[6-18]

(2) The lateral view of the foot and ankle: detects the amount of vertical displacement of the tuberosity of the calcaneus with disturbance of the different calcanean angles in relation to other bones and to the ground.[18]

There are different six calcanean angles [18] :(Fig. 10, 11)

1. **Tuber Joint angle (TJA) or Bohler's angle:** Normally it measures 20° - 40° and is reduced, obliterated or reversed in intra or extra-articular displaced fractures.[18, 25] (Fig. 11,12)

2. **Gissane's or crucial angle (GA):** Lies between the plane of anterior and posterior articular facets and measures 120°-145° (± 15°).[26, 27] It increases with destruction or depression of the posterior subtalar joint.[18]

3. **Calcanean compression angle (CCA):** It represents the height of the calcaneus and its reduction occurs in collapse and comminution of the bone.

4. **Talo-calcanean angle (TCA):** It measures the inclination of the talus over the calcaneus ie the angle between the long axes of the two bones.