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Review

Talar fractures: radiological and CT evaluation and classification systems

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Summary. *Introduction*: The talus is the second largest bone of the foot. It is fundamental to ensure normal ankle-foot movements as it connects the leg and the foot. Talar fractures are usually due to high energy traumas (road accidents, high level falls). They are not common as they account for 3-5% of ankle and foot fractures and 0.85% of all body fractures. However, talar fractures not correctly diagnosed and treated can lead to avascular necrosis of the astragalus, pseudoarthrosis, early osteoarthrisis and ankle instability, declining the quality of life of patients. *Methods:* A PubMed search was performed using the terms "talus" "talus AND radiology", "talar fractures", and "talar fractures classification", selecting articles published in the last 98 years. We selected articles about pre-treatment and post-surgery talar fractures diagnostic imaging. We also selected articles about talar fractures complications and traumatic talar dislocations. Case reports have not been included. *Aim of the work*: to describe radiological evaluations, classification systems, and biomechanical patterns involved in talar fractures. Also we will briefly describe talar fractures complications and treatment option and strategies. *Conclusions:* This work suggests a radiological approach aimed to classify talar fractures and guide treatment strategies, improving patient outcomes. (www.actabiomedica.it)

Key words: trauma, trauma imaging, talus, talar fractures, classification, radiology, biomechanics, conventional radiography, CT

Introduction

The talus or talo is the second largest bone of the foot. The name "talo" derives from the mythical giant Talos, a bronze giant from Crete defeated by Jason and the Argonauts receding his only vein that reaches the neck from the ankle (1).

The talus can be divided in three parts: an head, a neck, and a body . The body has three processes: posterior, lateral and medial process.

The talus is fundamental to ensure the normal ankle-foot biomechanic as it connects the leg and the foot through the tibio-talar joint, the leg and the hindfoot through the sub-talar joint and the midfoot to the hindfoot through the articulation of Chopart (2).

About two thirds of the talus is covered with cartilage. Only the area around the talar neck and the posterior aspect of the body are not covered so as to allow periosteal blood supply. Vascular supply to the astragalus originates from three vascular systems: the posterior tibial artery, the dorsalis pedis artery and the perforating fibular artery (3, 4). The talus has not tendinous insertion. Because of these peculiar characteristics, talar fractures not correctly diagnosed and treated can lead to Avascular Necrosis (AVN) and early osteoarthrosis (5, 6).

The talus is a weight bearing bone, and in healthy subjects it is very resistant to traumas as it has very thick subchondral bone. Strong forces are required to produce talar fractures. One of the first series of talar fractures were reported in pilots and parachutists of the Royal Air Force during the First World War, hence the term "aviator's astragalus" (7).

Nowadays talar fractures are not common, they account for 3-5% of ankle and foot fractures and 0.85% of all body fractures. They are usually the consequence of high energy traumas (road accidents, high level falls). The majority of patients show other associated fractures, such as in the ankle or in the foot or in other parts of the body (8-10).

Common risk factors are osteoporosis, diabetes mellitus, peripheral neuropathy, osteomalacia, and long-term immunosuppressive therapy.

From the clinical point of view, patients with talar fractures usually have swelling and visible hematoma in the ankle region and limited tibiotalar, subtalar and midtalar Range Of Motions (ROM). Frequently patients are unable to bear body weight on the affected extremity (10-15).

Biomechanical mechanisms leading to talar fractures are various, as there are different biomechanical patterns leading to different talar fractures.

Talar fractures can be classified according the anatomic region involved: head, neck, and body fractures. Body fractures are the most common (61%), talar head fractures are the least common (5%). They can also be classified in intra articular fractures and extra articular fractures (10, 16-20).

The most frequently used neck fractures classification is the one proposed by Hawkins LG in 1970, lately modified by Canale and Kelly in 1978 that includes four fracture types (21, 22).

The most used body fractures classification is the Sneppen classification, that divides talar body fractures in six mayor types (23, 24).

Talar fractures can occur isolated or they can be part of more complex conditions. Associated injuries can be the loss of normal anatomical relationship between ankle and foot bones, damages to the vascular supply systems and concomitant extra talar fractures.

First line diagnostic imaging is based on radiography and Multi Detector Computed Tomography (CT) scans, with Volume Rendering Technique (VRT) and Multi Parametric Reconstruction (MPR) (25-30). A correct and prompt diagnosis is mandatory to guide effective management decisions and optimize treatment outcomes (26, 31-35).

Talar fractures not correctly diagnosed and treated can lead to avascular necrosis of the astragalus, early osteoarthrosis and ankle instability, declining the quality of life of patients (36-40).

Radiologic assessment

Radiography is usually chosen as first exame to evaluate a suspected astragalus fracture. Radiography assessment is generally performed with three standard projections: antero-posterior (AP) and latero-lateral (LL) views of the ankle, and the so called "mortise view" (AP with 30°internal rotation of the foot). The mortise view allows a better visualisation of the lateral aspects of the talus with no superimposition of the fibular malleolus. AP, oblique, and lateral projections of the foot are also generally performed. Because of the superimposition of ankle and foot structures, radiography has low sensitivity and specificity for talar fractures. Moreover, patients are frequently in critical conditions and it is not always possible to obtain good quality radiographs (31, 41-45).

Multi Detector Computed Tomography (MDCT) images have both higher sensibility and specificity than radiography. CT images can be more easily interpreted even when anatomical relations are subverted. MPR images should be performed along the anatomical axes of the foot (46-50). MDCT evaluation with MPR and VRT reconstruction are recommended to best assess fracture(s), anatomical relationship, degree of comminution (51), eventual intra articular loose bodies. CT is also needed to guide management decisions and for surgical planning (23, 52).

Ultrasound (US) and Magnetic Resonance Imaging (MRI) have limited role in the acute setting of astragalus fractures (53-60). They can be useful in a second look for the evaluation of soft-tissue injury, especially for the evaluation of the posterior talo-tibial ligament (61).

Fractures classification

Talar fractures are classified according to anatomic region: head, neck, and body.

Body fractures are the most common and talar head fractures are the least common (10, 16). Talar body fractures account for 61%, neck fractures account for 5% and head fractures account for 5%; 29% of talar fractures involve head and neck, neck and body or all the three components (16, 62-65).

Talar body fractures

Talar body fractures include in order of frequency (16) fractures of the talar dome, fractures of the lateral and posterior processes and true fractures of the talar body (66). The reported incidence of talar body ranges from 13% to 61% (16, 67). Sneppen analyzed fifty-one talus-fractured patients for an average time of 23 months after treatment. He proposed what is nowadays known as the most used classification for talar body fractures (24):

- Type A: compression or osteochondral dome fractures
- Type B: coronal shear fractures.
- Type C: sagittal shear fractures
- Type D: posterior tubercle fractures
- Type E: lateral tubercle fractures
- Tipe F: crush comminuted fractures

Different types of lesions have different treatment and prognosis.

Osteochondral fractures of the talar dome

Osteochondral fractures of the talar dome are the most common type of body fractures (16). This kind of fracture generally results from an impaction injury, which damages the articular cartilage and subchondral bone (68, 69) (fig. 1). Fractures of the talar dome may be difficult to detect in standard radiographs. Dale et al retrospectively reviewed 132 talar fractures detected in 122 patients over a period of 1,5 years: they found that approximately 31% of talar dome compression fractures were not diagnosed during the initial radiographies (16).

Osteochondral fractures (OCF) account for about 1% of all talar fractures. The most commonly used classification for OCF was presented by Berndt and Harty (70) in 1959, with an additional stage described by Scranton and McDermott in 2001 (71).

The modified Berndt and Harty classification counts 5 stages:

Stage 1: subchondral bone compression.

Stage 2: incomplete separation of the fragments.

Stage 3: complete separation of the fragments with no displacement.

Stage 4: complete separation of the fragments with displacement.

Stage 5: large cyst below the articular surface.

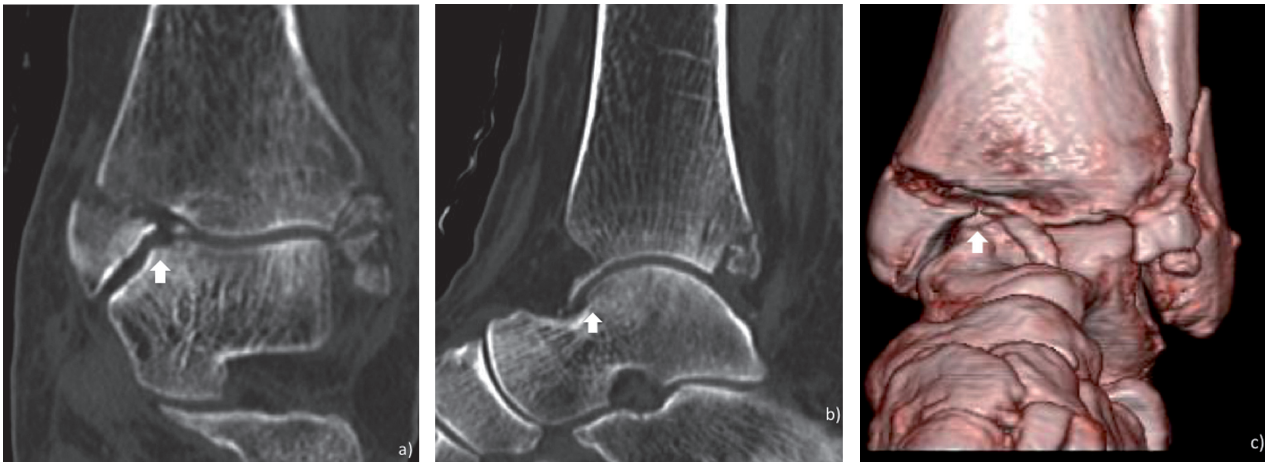

Figure 1. Coronal MPR shows an osteochondral medial defect of the talar dome (A, white arrow) associated with a «trimalleolar fracture». Sagittal MPR (B) and VRT (C) reconstructions better visualize the displaced fragments (white arrow)

Lateral lesions are usually shallow and commonly caused by dorsiflexion and inversion injuries.

Medial lesions are generally less symptomatic, and typically deeper than lateral lesions; they probably result from plantar flexion and inversion injuries.

Stable and nondisplaced OCF have good prognosis; on the other hand displaced and unstable lesions frequently lead to AVN (15, 72-75).

Posterior process body fractures

This kind of fracture more frequently involves the lateral part of the posterior tubercle (so called "Shepherd fracture"); fractures of the medial part of the tubercle (Cedell fracture) are less frequent (61). Posterior process fractures result from the compression of the posterior process between tibia and calcaneus caused by forced plantar flexion, or from direct trauma to the hind foot. Forced plantar flexion can also result in rupture of the syndesmosis of an os trigonum (76). In the Paulos LE experience, based on 20 patients collected from an orthopaedic sports medicine center, clinical examination was strongly diagnostic: all patients with a posterior process fracture came with significant deep palpable tenderness located posterior to the astragalus and anterior to the Achilles tendon. Also, all patients referred hindfoot pain exacerbated from passive plantar flexion. Pain could also be seen with passive handling of the toe because of the anatomic location of flexor hallucis longus tendon in the hindfoot near the posterior lateral tubercle. Posterior process fractures must be differentiated from an os trigonum – an accessory bone located posteriorly to the talus (77). The os trigonum is present in approximately 7% of general population and it is bilateral in 66% of the cases. In conventional radiographies, posterior process fractures have irregular edges and do fit with a defect on the adjacent posterior part of the talus. On the other hand, an os trigonum has round or oval shape and smooth edges, with complete cortical covering and does not fit with the talus (78) (fig. 2).

Conservative treatment is usually chosen for posterior process fractures; if conservative treatment fails, surgical excision of the fragment may be necessary (76, 79, 80).

Lateral process body fractures

This kind of fracture is the second most frequent of talus body. Isolated lateral process fractures are usually difficult to detect during standard initial radiographs (81). Most of the patients are diagnosed after a period of persistent pain on the fibular side of the ankle, exacerbated by forced dorsiflexion of the foot (82). They can occur as isolated fracture or as a component of more complex ankle fractures. These fractures can be seen as an interruption of the cortex of the lateral process; however, as reported by Ebraheim et Al, CT is often necessary for a safe diagnosis: in the opinion of these authors, based on the study of fractured process of the talus in 10 patients, CT imaging is necessary to better assess the size of the fragment (s), degree of displacement, and the plurifragmentation of the fractured process (83). This kind of fractures result from traumas causing dorsiflexion and external rotation of the foot, and they are particularly common in snowboarders (84-86). In Lee's opinion these fracture occur when the foot is dorsiflexed and inverted (87). Kirkpatrick analyzed 3213 snowboarding injuries collected from 12 Colorado ski resorts between 1988 and 1995. His study concludes that these fractures account for approximately 34% of all ankle injuries and snowboarders are 17 times more likely to experience lateral process fractures than the general population. The most common mechanism of injuries is twisting movements, followed by accidents occurred while getting on or getting off the lift with only one foot hooked to the snowboard, and collisions with trees or other skiers (84, 88). However, lateral process fractures can also result from road accidents or high level falls (16).

Lateral process fractures have been classified by Morrison (89) in three types:

- type 1: simple (fig. 3)
- type 2: comminute fracture (fig. 4)
- type 3: cortical avulsion fracture (fig. 5)

Type 2 fractures have been further subdivided by Hawkins (82) according to the displacement of the fragment in:

- type 2a: <2 mm displacement of fracture fragments
- type 2b: >2 mm displacement of fracture fragments

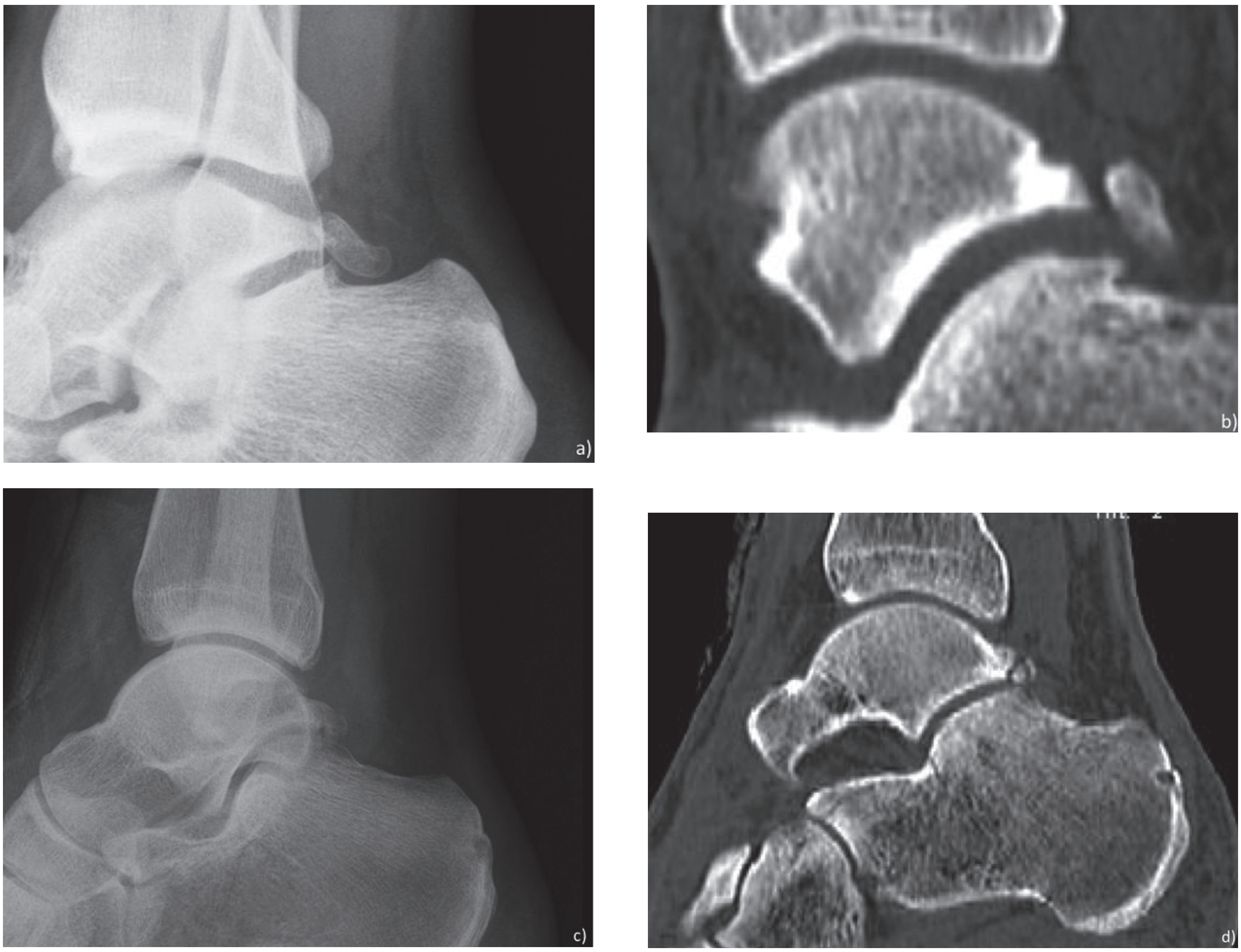

Figure 2. Differential diagnosis between os trigonum and posterior process fracture. Os trigonum (A, B) has round or oval shape and smooth edges, with complete cortical covering and does not fit with the posterior aspect of the talus. Posterior process fractures (C, D) have irregular edges and do fit with a defect in to the adjacent posterior part of the talus

Simple fractures and fractures with a less than 2 mm displacement can be managed conservatively. If the displacement is greater than 2 mm open reduction and internal fixation (ORIF) is recommended (90). Small comminuted fragments should be removed (79, 91). Late diagnosis of this kind of fractures can lead to pseudoarthrosis, joint instability and osteoarthritis, requiring subtalar fusion.

True talar body fractures

Usually resulting from high-energy trauma, the incidence of this kind of lesion is difficult to estimate as they commonly occur associated to other injuries. They can involve the talocalcaneal joint, the tibiotalar joint, or both. Different fracture patterns have been reported, ranging from simple two-fragment fractures to comminuted injuries (fig. 6 and fig. 7).

Fractures of the talar body often result from high energy traumas - usually a high-level fall or motor vehicle accident - leading to axial loading on a dorsiflexed foot. Crush comminuted talar body fractures have the worst prognosis of all talar body injuries (92). They generally result from high-energy traumas and an open wound is frequently associated. In case of bone loss and fragments dislocation the risk of avascular necrosis is high.

Initial diagnosis can be made with standard AP, lateral and the so called “mortise view” radiography;

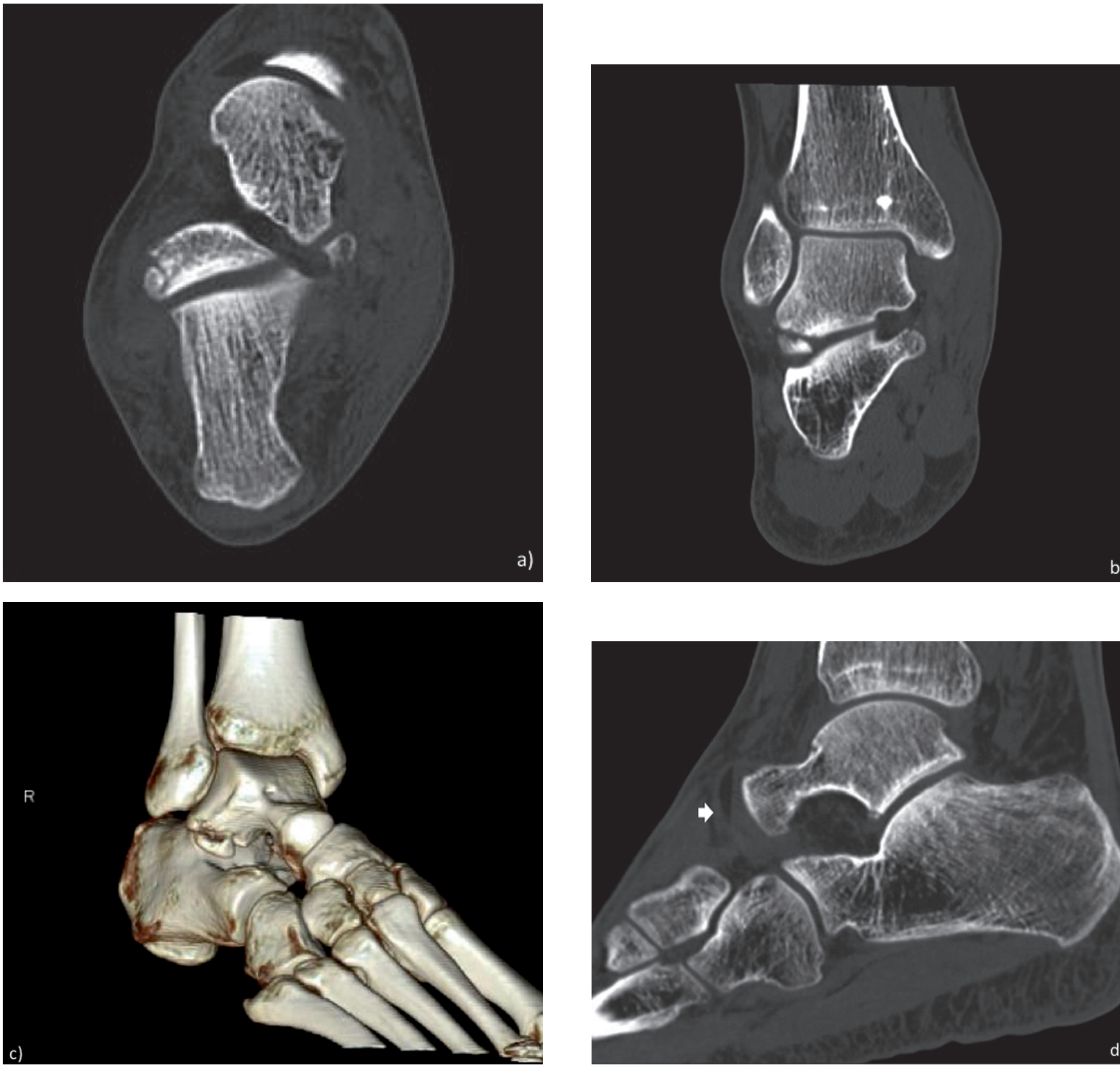

Figure 3. Simple Lateral Process Fracture. Basal Axial CT scans (A), Multi Planar Reconstructions (B, D) and VRT reconstruction (C). The detached fragment is better visualized in the coronal plane (B) than in the axial plane. VRT reconstruction (C) permits clear visualization of anatomical relationships. In the sagittal MPR (D) a little lipohemarthrosis can be seen at the level of the anterior talo-navicular ligament (white arrow)

however, subsequent CT with MPR is recommended to assess the degree of comminution, anatomical relationship and for surgical planning (23, 25, 72).

Talar body fractures' treating aims to restore congruity of the tibiotalar and talocalcaneal joints. Conservative management is reserved for nondisplaced fractures, even if the majority of talar body fractures are displaced and will require operative treatment. Complications such as AVN and posttraumatic osteoarthritis are common. Associated talar neck and open fractures increase the likelihood of complications (23, 72).

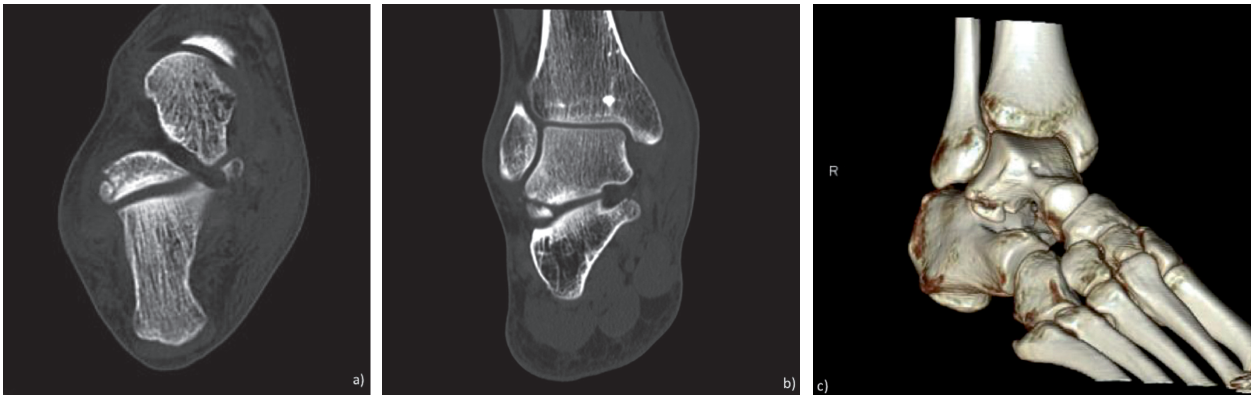

Figure 4. Comminuted lateral process fracture. AP radiograph (A), coronal CT MPR (B) and VRT reconstruction (C)

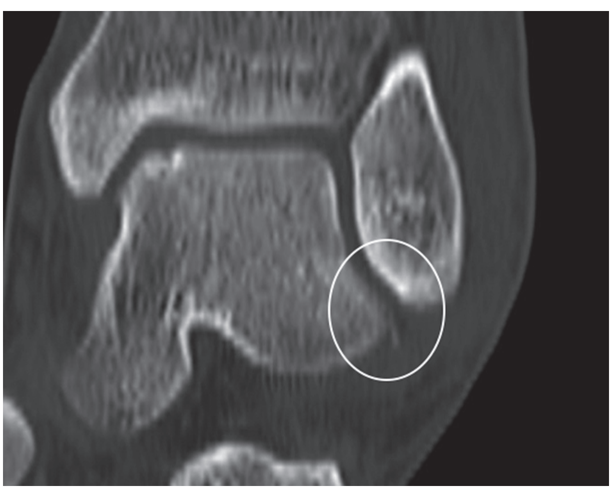

Figure 5. Lateral Process cortical avulsion (coronal CT MPR)

Talar neck fractures

These fractures were historically considered as the most frequent of the talus (16, 21, 93). Nevertheless neck fractures were recently proved by Dale JD to constitute only 5% of all talar fractures (16). The inconsistency probably is due to the lack of clear differentiation between talar neck and talar body fractures. The widely accepted definition is the one proposed by Inokuchi S, who examined 215 fractures of the talus; this classification is based on the location of the inferior fracture line. If the fracture line is anterior or inferior to the lateral process of the talus and the talar dome cartilage, it is classified as a talar neck fracture (94) (fig. 8). The most common causal mechanism of this kind of frac-

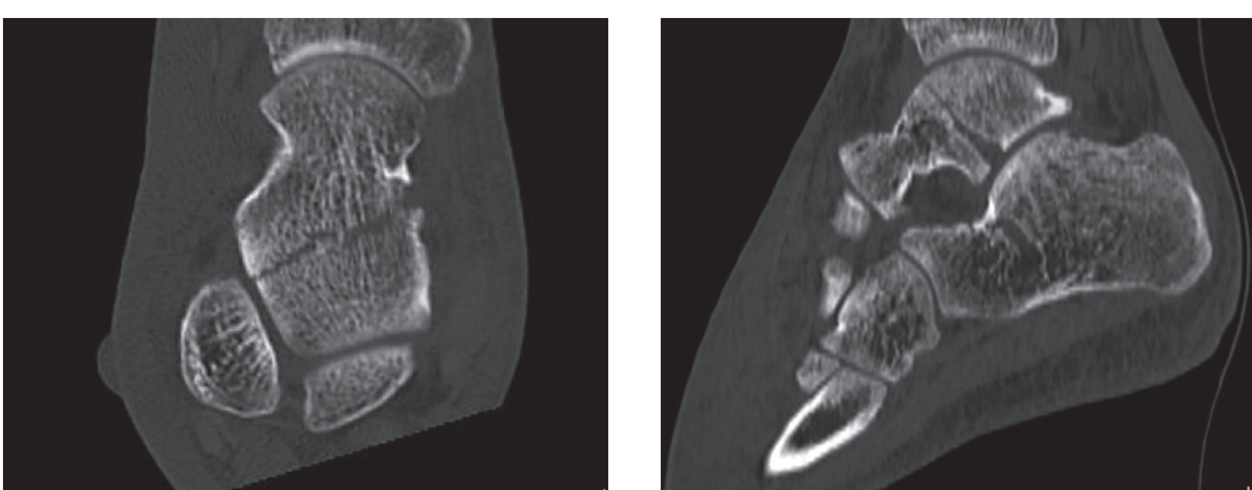

Figure 6. Two fragments body fracture. Axial CT scan (A) and sagittal Multi Planar Reconstruction

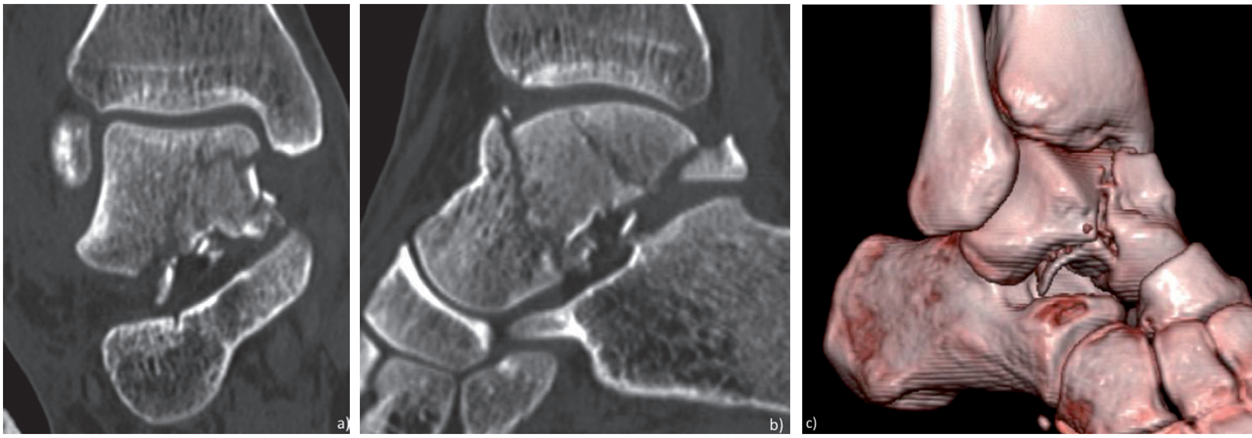

Figure 7. Complex body fractures. Coronal (A) and sagittal (B) Multi Planar reconstructions and Volume Rendering Reconstruction

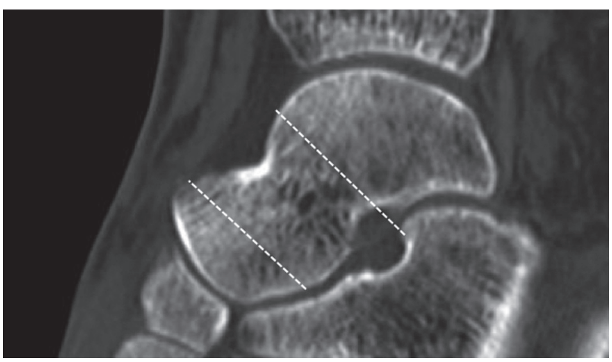

Figure 8. Differentiation between talar neck and talar body fractures

ture is forced dorsiflexion of the talus against the tibia. A stronger force may result in subtalar or tibiotalar dislocations. Peterson et al experimented mechanisms of neck fractures on twenty cadavers. They found that maximal stress concentration in the collum tali was necessary to fracture the talus itself. The authors achieved this eliminating all movements in the ankle joint and fixing the body of the talus as a cantilever between the tibia and the calcaneus. This was done by applying pre-tension on the foot in a shoe by four rigging screws fixed to the sole (95). The first series of talar neck fractures was described in airplane pilots during World War I and termed "aviator astragalus" by Anderson(7) in 1919. Nowadays, such injuries usually result from high-level falls and road accidents and they are frequently associated with more complex injuries of the foot (16).

The first classification system for talar neck fractures was described by Hawkins in 1970 after the evaluation of fifty-seven fractures detected in fifty-five patients (21). The Hawkins classification was subsequently modified by Canale and Kelly in 1978 after the analysis of seventy-one fractures of the neck (22) (tab. 1).

Type I is a nondisplaced fracture (fig. 9). As the fracture line may be parallel to the x-ray beam, this type of fracture may be difficult to detect. Usually only

Table 1. The modified Hawkins-Canale classification of talar neck fracture with associated risk of ostheonecrosis

Hawkins-Canale Classification		
Fracture type	Description	Risk of Osteonecrosis (%)
I	Nondisplaced talar neck fracture	0-15
II	Talar neck fracture and talocalcaneal dislocation	20-50
III	Talar neck fracture, talocalcaneal dislocation and tibiotalar dislocation	100
IV	Talar neck fracture and disruption of all talar articulations	100

Figure 9. Type I neck fracture. LL ankle (A) and oblique foot (B) radiographs, sagittal CT MPR (C) and VRT reconstruction (D)

the blood supply coming from the dorsolateral aspect of the neck is involved, while the other two blood supply systems are normally intact, so the risk of AVN is low (0-15%) (22, 37).

Type II is a neck fracture with subluxation or dislocation of the subtalar joint, frequently associated with a medial dislocation and an open wound is commonly present. The tibiotalar and talonavicular joints remain congruent. In this type of injuries at least two of the three blood supply systems are involved: the proximal talar neck branches (as in type I), as well as vessels entering inferiorly in the roof of the sinus tarsi and tarsal canal. Even the third main source of blood, which enters via the medial surface of the body, can be injured, so the risk of AVN is higher than in type I (20-50%) (22, 37).

Type III is a type II fracture with subluxation/dislocation of the subtalar joint and subluxation/dislocation of the tibiotalar joints. The talonavicular joint does not dislocate.

The double dislocation with postero-medial extrusion of the talus places the posterior tibial neurovascular bundle at high risk (22, 96). All three of the major sources of blood supply to the talus are commonly injured with type III talar neck fractures and the risk of AVN is very high (up to 100%) (22, 37).

Type IV is a fracture with subluxation or dislocation of the subtalar, tibiotalar, and talonavicular joints. In this injury, interruption of the blood supply to all the talus (body, neck, head) is possible because all the three blood supply systems can be injured, so the risk of AVN is very high (up to 100%) (22, 37).

In the initial evaluation of talar neck fracture standard AP, lateral, and oblique radiographs of the ankle and foot should be obtained. Talar neck's fractures are best appreciated on ankle's lateral views, especially in the case of vertical displacement (22, 37). CT is usually performed to better delineate fracture(s) and displacement, as well as to find radiographically occult fractures (i.e. small avulsion fractures, posterior and lateral processes fractures, osteochondral defects) (16). Only nondisplaced talar neck fractures can be treated conservatively, so every displacement of the fragments has to be detected. Recent studies suggest that fracture displacement, degree of comminution, extent of soft tissue injury, and the quality of surgical reduction influence the development of osteonecrosis and the overall result (97-100). Type II injuries are usually surgically reduced. For type III and IV fractures, closed reduction may be initially attempted to relieve skin tension and minimize soft-tissue injury; however definitive treatment consists of open reduction and internal fixation (101).

Talar head fractures

Talar head fractures involve the articular surface of the talus at the talonavicular articulation, often accompanied by dislocation or subluxation and adjacent bone fractures. Dale JD retrospectively reviews 132 talar fractures detected in 122 patients and stated that these are the least common fractures of the talus, accounting for 5% of all talar fractures (16). Coltart WD analyzed 228 injuries to talus treated by surgeons working in orthopaedic units of the Royal Air Force between 1940 and 1945. He described two distinct talar head fracture patterns: a crush injury to the articular surface with significant comminution and a shear fracture (102) (fig. 10).

Patients with isolated talar head fractures usually present with pain, swelling and tenderness to palpation over the talar head. Also painful range of motion at the midtarsal joint is usually present (102).

Fractures of the talar head are usually seen on AP, oblique, and lateral radiographs of the foot. The profile of the talar head should be carefully evaluated on all the radiographs to diagnose even subtle fracture and displacement. After a talar head injury is identified or suspected, CT evaluation with MPR should be performed to better evaluate the degree of fragments displacement and the extension of the fracture line. Simple nondisplaced talar head it results that talar dislocations more frequently occur with associated bone fractures (103).

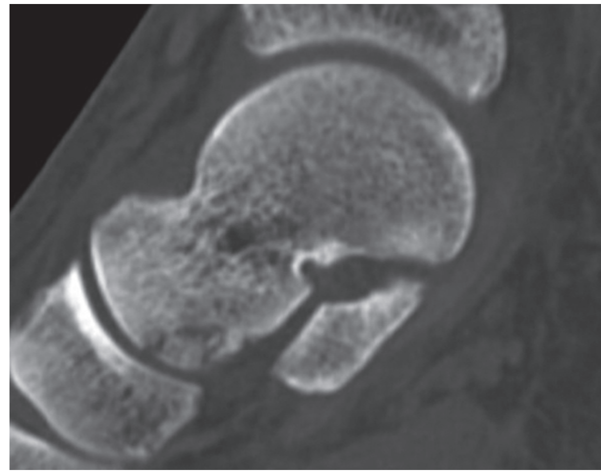

Figure 10. Simple shear fracture of the head (sagittal CT MPR)

Peritalar dislocation

Peritalar dislocation is not common. It is defined as the contemporary loss of normal anatomic relations between the talus, the navicular bone, and calcaneus, while the subtalar and calcaneocuboid joints remain congruent (104). This dislocation is also known as hindfoot dislocation. The causal mechanism could be either a foot plantar-flexing trauma with inversional forces, determining medial subtalar joint dislocation (80%) or with eversional forces, determining lateral dislocation (17%) (105). Rare anterior and posterior dislocations have also been reported (105-107). Subtalar dislocation can be either caused by low-energy trauma, such as trauma occurring in jumping sports as volleyball or basketball, or by high-energy trauma (road accidents, high level falls) (108). Lateral subtalar dislocations result from eversional forces, displacing the distal foot laterally to the talus. They are often associated with bone fractures, with a high likelihood

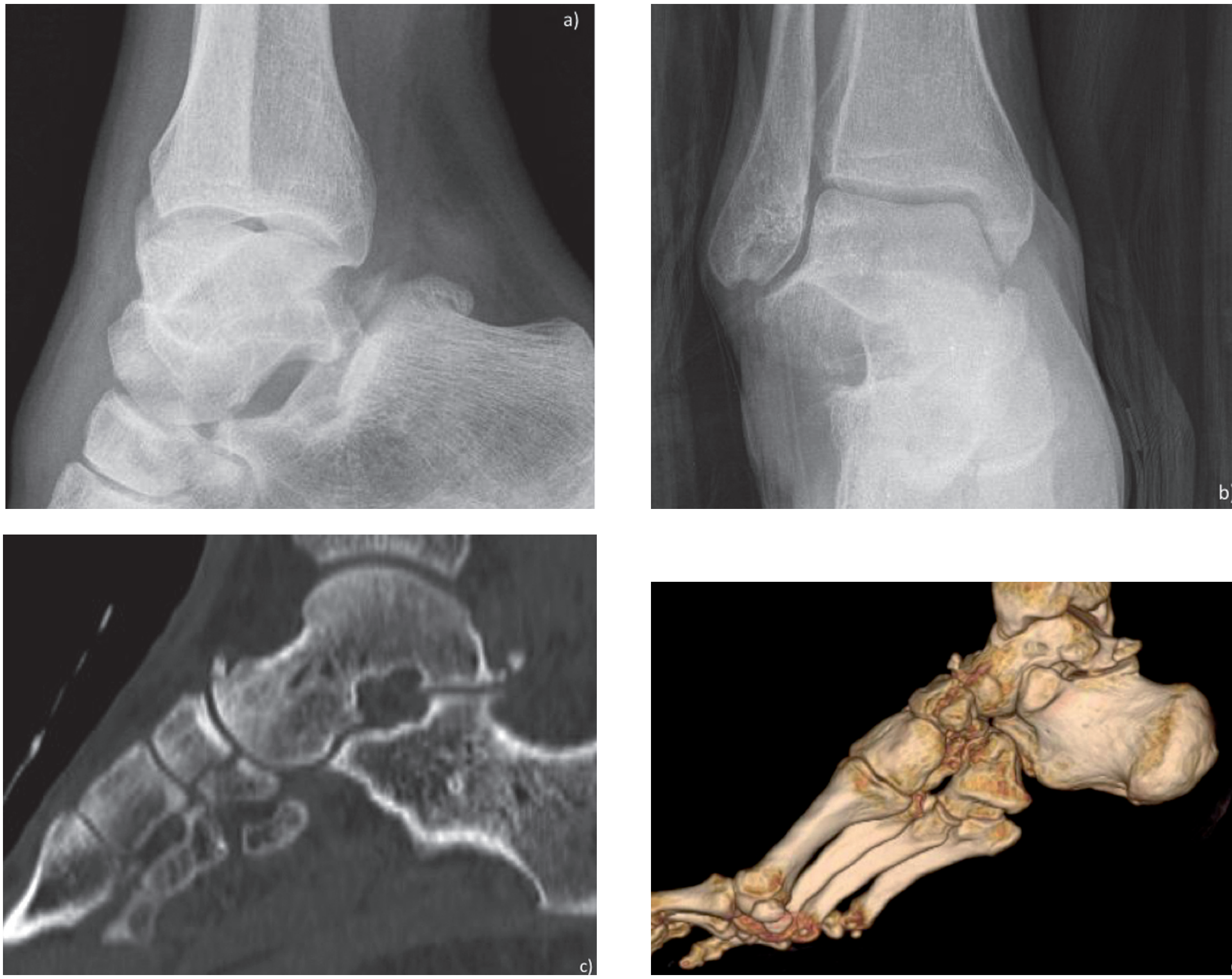

Figure 11. Total talar dislocation. Pre-reduction radiographs (A, B) and post-reduction sagittal CT MPR (C) and VRT reconstruction (D). Post-reduction CT with multiplanar and volume rendering technique reconstructions permits a better detection of displaced fragments, delineation of anatomic relationship and has a higher sensitivity for associated fractures (see the navicular simple fracture in C, not clearly detectable in A)

ratio of joint instability and AVN. Prompt reduction is mandatory to reduce neurovascular damage (109).

The diagnosis of subtalar dislocation is usually made on AP, lateral, and oblique radiographs of the ankle.

After reduction, antero-posterior, lateral radiographs and the so called "mortise view" should be obtained to confirm the results. CT examination should be performed too. CT with multiplanar and volume rendering reconstruction permits a better delineation of anatomic relationship and has a higher sensitivity for associated fractures. Hindfoot fractures frequently occur in association to subtalar dislocations; there could be fractures of the posterior process of the talus, osteochondral fractures and calcaneus fractures. Osteochondral lesions are particularly frequent (12-38% of medial dislocations and up to 100% of lateral dislocations) (103, 110).

Total dislocation

Total dislocation is a very serious and extremely rare condition, accounting for 0.06% of all foot dislocations and 2% of talar fracture-dislocations (111) (fig. 11). Total dislocation usually results from high-energy trauma. Also known as pan-talar dislocation, It is the dislocation of the talus from all its articulations (112). It usually comes with open wound. Fractures of the foot bones are frequently associated. However, a rare subtype with no associated fracture has been described.

X-Rays can be initially obtained, but subsequent CT examination with multiplanar and volume rendering examination is mandatory. This injury has a high risk of infection and AVN. Total dislocation can be treated with talectomy and arthrodesis; reimplantation of the extruded talus can be attempt (112).

Conclusion

The talus has a complex anatomy and biomechanics. Conventional Radiography is the first line methodic in the evaluation of a potential talar fracture; however CT scans with MPR and VRT reconstructions are necessary to accurately assess and classify talar fractures. A correct and prompt diagnosis is mandatory to guide effective management decisions and optimize treatment outcomes.

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