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Review Article

Review of running injuries of the foot and ankle: clinical presentation and SPECT-CT imaging patterns

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Abstract: Distance running is among the fastest growing sports, with record registration to marathons worldwide. It is estimated that more than half of recreational runners will experience injuries related to the practice of their sport. Three-phase bone scintigraphy is a very sensitive tool to identify sports injury, allowing imaging of hyperemia, stress reaction, enthesopathy and fractures, often before abnormalities can be detected on conventional anatomical modalities. In this article, we review the most common running related injuries and their imaging findings on bone scintigraphy with SPECT-CT.

Keywords: Bone scintigraphy, SPECT, SPECT-CT, sports injury, running, stress fracture, enthesopathy

Introduction

Humans have been running long distances for millions of years [1]. Over time, many features of energetics, strength, stabilization and thermoregulation have evolved, allowing humans to perform remarkably well at endurance running [1, 2]. Nevertheless, incidence of injury has been reported to be as high as 30-80% per year among endurance runners, with foot and ankle injuries representing approximately a quarter of these injuries [3, 4]. Bone scintigraphy is a sensitive diagnostic tool for both acute and chronic sports injuries [5], with radiotracer uptake determined by local blood flow and the rate of bone turn over [6]. This allows detection of pathology at a very early stage, often before structural changes can be detected on conventional anatomical imaging modalities such as x-ray and computed tomography (CT). Furthermore, the addition of single photon emission computed tomography (SPECT) and SPECT-CT allows for better localization and characterization of bone pathology, with resultant increase in diagnostic accuracy [7]. Although MRI is becoming the imaging modality of choice for sport injuries, recognition of these pathologies on bone scintigraphy remains important. Indeed, bone scintigraphy is still performed in equivocal cases, MRI is not always readily available, and these pathologies can present as incidental findings in studies performed for unrelated reasons. In this article, we review the mechanisms and clinical presentations of different foot and ankle running injuries. We also present the SPECT-CT imaging findings of bone scintigraphy performed with 99m-technetium-labelled methylene diphosphonate (^{99m}Tc-MDP).

Running injuries

Stress fractures

Stress fractures are a common cause of pain in runners, accounting for up to 16% of injuries [8]. Conversely, stress fractures are most commonly encountered in runners [9]. Stress fractures are due to repeated abnormal strain from chronic weight-bearing activity [10]. This strain causes imbalance between osteoclastic and osteoblastic activity, leading to micro fractures, which may eventually progress to cortical break. Different intrinsic and extrinsic risk factors have been associated with increased risk of stress fractures (summarized in **Table 1**).

Stress fractures can affect various bones of the lower extremities and pelvis. In runners, the most commonly affected bone is the tibia, rep-

Table 1. Risk factors associated with stress fractures

Intrinsic risk factors	Extrinsic risk factors
Female sex [63]	Running [8]
Amenorrhea [64, 65]	Change of surface, volume or intensity of training [63, 73]
Low bone mineral density [66]	Inappropriate or worn footwear [74]
Leg length discrepancies [63]	Low vitamin D [75]
Valgus knees [67]	Smoking [76]
Forefoot varus [68-70]	
Restricted dorsiflexion of the ankle joint [68-70]	
Small calf circumference [68-70]	
External rotation of the hip greater than 65 degrees [68-70]	
Pes planus [71, 72]	
Pes cavus [71, 72]	

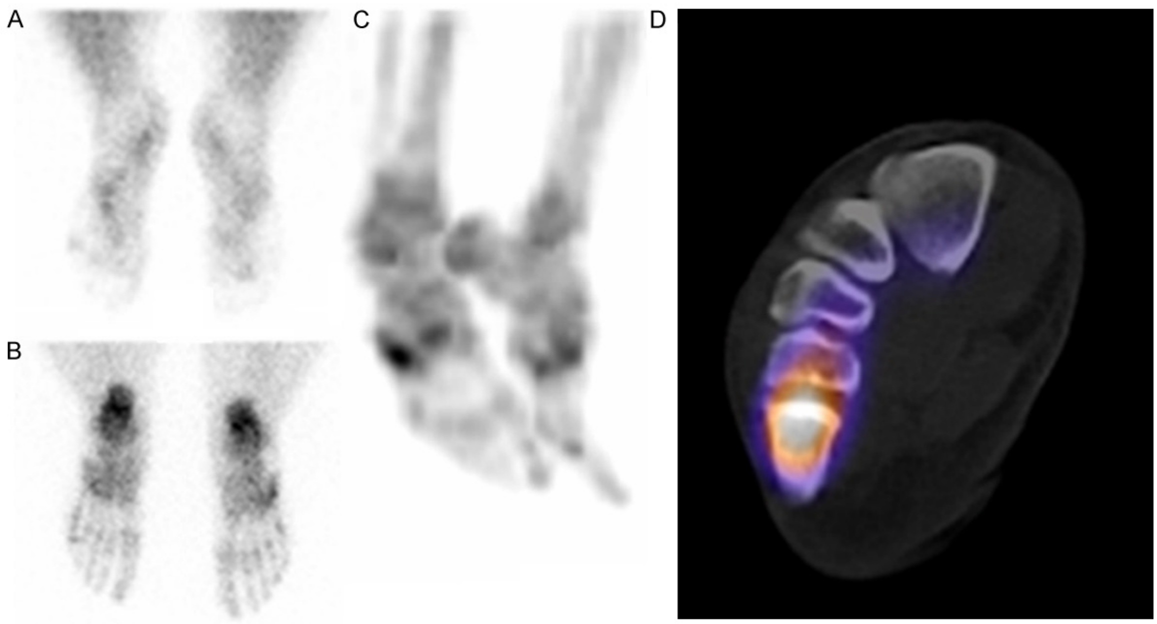


Figure 1. Plantar blood pool (A) images demonstrate relatively symmetrical activity in both feet. Delayed plantar bone images (B) show mildly increased uptake in the right 5th metatarsal and cuboid bone area. Maximal intensity projection (C) and axial (D) SPECT-CT images localize the uptake in the fifth proximal metatarsal, consistent with a stress fracture.

resenting approximately 40% of stress fractures, followed by the fibula which represents approximately a quarter of cases [3, 11]. Foot and ankle pathology is present in approximately a quarter of cases [11, 12]. 55% of stress fractures of the foot and ankle occur in the metatarsals, predominantly affecting the first and second metatarsals. 30% affect the lateral malleolus and 9% the medial malleolus. The calcaneus, talus, navicular and sesamoid account for the remaining 6% [13]. Navicular stress fractures are less frequent in long distance runners but tend to afflict sprinters, hurdlers and middle distance runners [11].

Patients with stress fracture typically present with localized pain without history of trauma. Initially, the pain occurs during training, usually late in the run. Without intervention, the pain progresses and presents earlier in the run and may eventually be present at rest [9]. Even though it is relatively insensitive, initial investigation should always consist of a plain radiograph as it is easily available and inexpensive. If the initial plain film is negative, MRI is the next modality of choice. Nevertheless, bone scan can be useful when radiographic interpretation is discordant with clinical findings or when MRI is unavailable [14]. Abnormal uptake

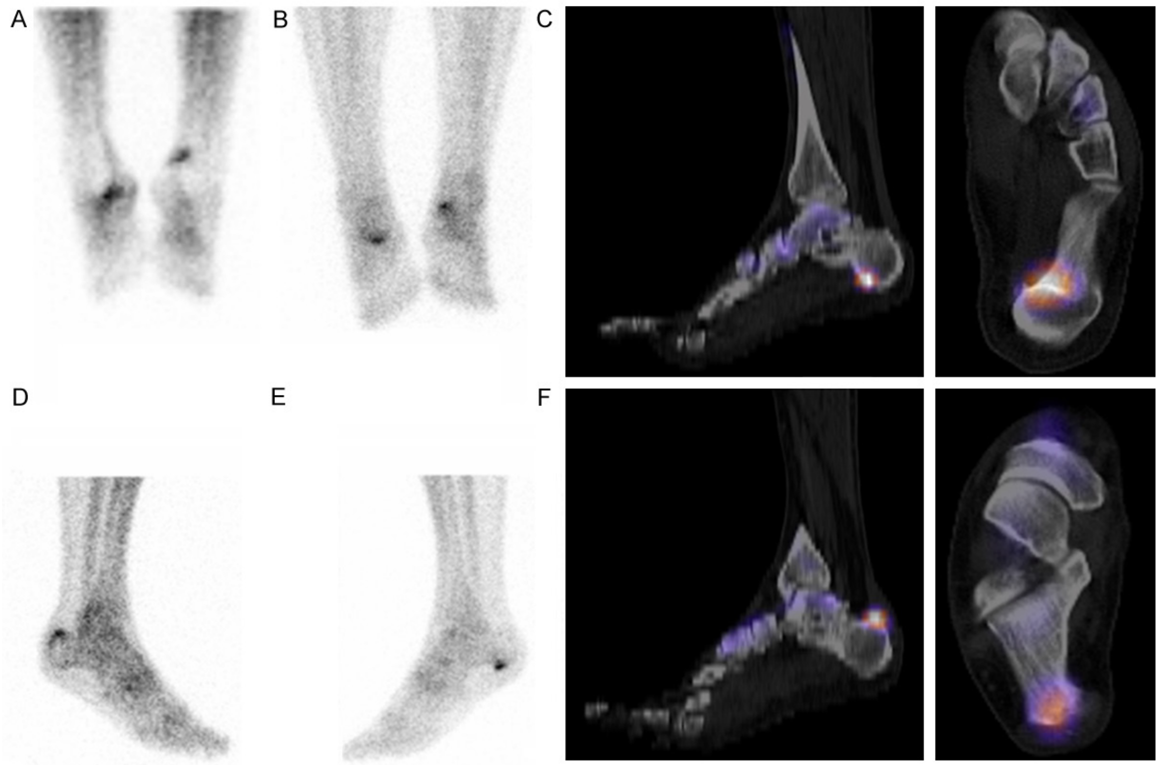


Figure 2. Posterior blood pool image (A) shows hyperemia in the posterior aspect of the right calcaneus and plantar aspect of the left calcaneus. Delayed posterior (B) and lateral images of the right (D) and left (E) foot demonstrate increased uptake in a similar distribution. Sagittal and axial SPECT-CT images of the left foot (C) demonstrate increased activity at the calcaneal tuberosity consistent with plantar fasciitis. Sagittal and axial SPECT-CT images of the right foot (F) show increased uptake at the Achilles' insertion site in the calcaneus, consistent with Achilles enthesopathy.

on bone scintigraphy is seen 6 to 72 hours after onset of symptoms [8]. Stress fractures can be divided between high-risk and low-risk stress fractures, based on anatomical location, prognosis, and management [15, 16].

High risk: High-risk stress fractures in the foot and ankle include navicular and proximal fifth metatarsal fractures. Navicular stress fractures are relatively frequent in runners due to its poor vascularization [17]. When cortical disruption is present, orthopedic consultation is warranted [18]. Proximal fifth metatarsal stress fracture is not frequent but important to identify because of a high rate of delayed healing and non-union in up to two-thirds of cases [19, 20]. Fractures involving the metaphyseal-diaphyseal junction of the fifth metatarsal are referred to as "Jones" fractures. Treatment options for non-displaced Jones fracture include non-weight-bearing cast immobilization and surgical intervention [21]. Bone scintigraphy demonstrates focal increased uptake on delayed imaging (**Figure 1**). Given the complex anatomy of the foot and ankle, SPECT and SPECT-CT allows for better fracture localization.

Plantar fasciitis

Plantar fasciitis (PF) is among the most common causes of heel pain in athletes, usually presenting as a sharp pain in the middle of the heel or foot arch. The pain is usually reproducible by palpation on physical examination. The plantar fascia consists of the connective tissue supporting the arch of the foot and connects the tuberosity of the calcaneus to the head of the metatarsals. PF is associated with a deficit in flexibility of the calf muscles and Achilles tendon as well as high arched feet [22, 23]. Other risk factors include overtraining, increased hill work, footwear with poor cushioning, worn footwear, increased running distance or intensity, and change in running surface [24]. The diagnosis of PF is usually based on clinical history and physical examination. However, imaging is

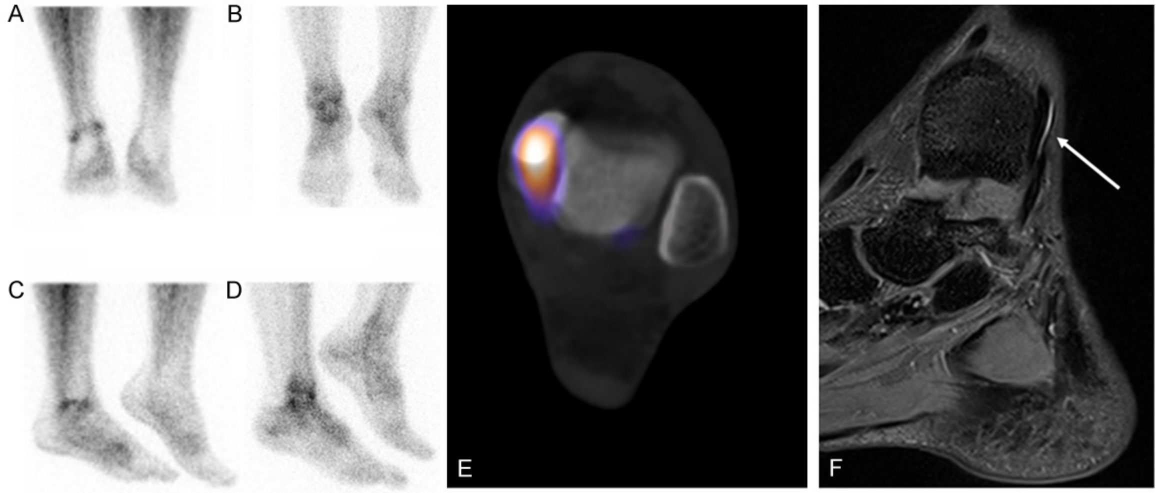


Figure 3. Posterior (A) and lateral (C) blood pool images demonstrate mild increased uptake over the left malleoli, consistent with mild hyperemia. Delayed planar posterior (B), lateral (D) and axial SPECT-CT (E) images show focal increased activity at the inferior aspect of medial malleolus, suggestive of malleolar periostitis due to posterior tibialis tendinosis. Sagittal PD fat suppressed weighted image (F) from subsequent MRI confirmed edema with mild tendinosis of the inframalleolar portion of the posterior tibial tendon (arrow).

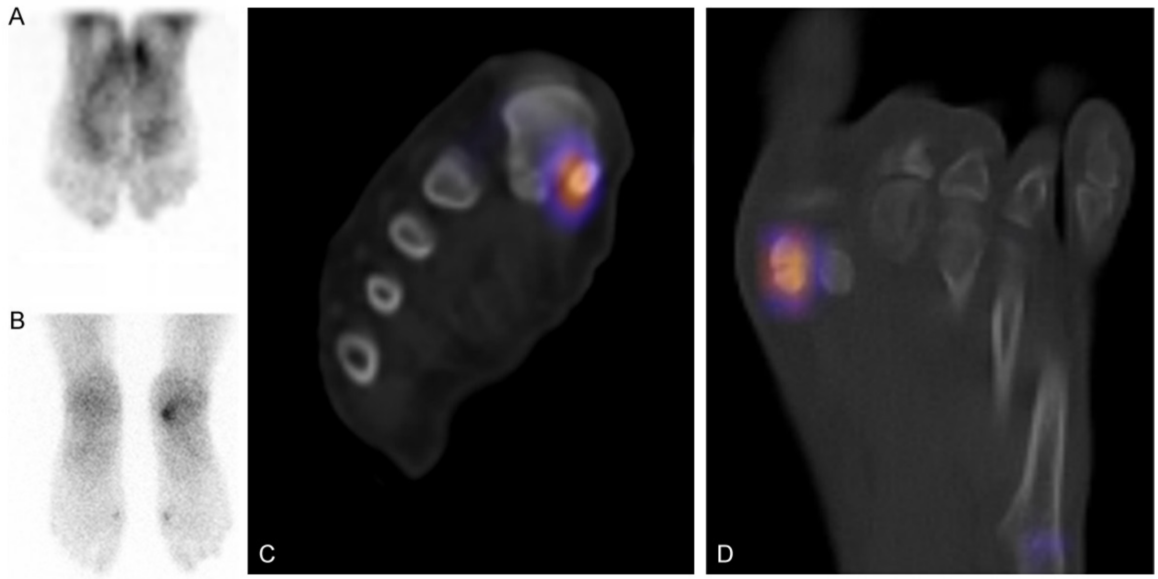


Figure 4. Focal increased uptake on delayed plantar image (B) and SPECT-CT (C) in the tibial sesamoid bones bilaterally without significantly increased activity on blood pool images (A), attributed to sesamoiditis. In this case, the focal increased uptake in the right talus corresponds to remote talar fracture. SPECT-CT (D) images of a different patient demonstrates focal increased uptake with associated fracture of the left tibial sesamoid bone.

occasionally necessary to differentiate PF from calcaneal stress fracture. Plain radiographs are neither sensitive nor specific, with a plantar calcaneal heel spur seen in half of symptomatic patients and in a quarter of asymptomatic patients [24]. On bone scintigraphy, PF presents as focal increased activity at the calcaneal tuberosity, the site of insertion of the plantar fascia (**Figure 2**). Not only can bone scintigraphy confirm the diagnosis of PF, it can also indicate the specific site of active inflammation, allowing guidance of corticosteroid injections [25]. Furthermore, it can be used to assess response to treatment, as demonstrated by decreased uptake after corticosteroid injections [26]. This is an important consideration

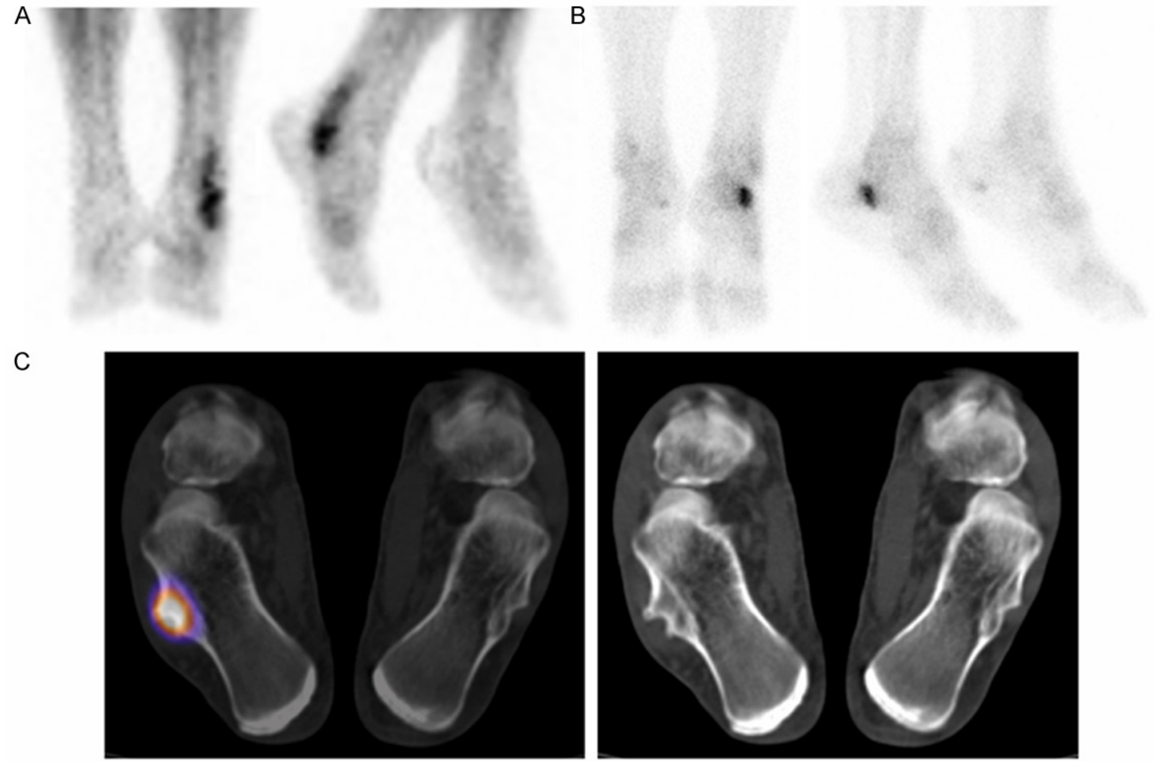


Figure 5. Posterior and lateral blood pool images (A) demonstrate hyperemia in the right lateral malleolar region. Delayed planar posterior and lateral images (B) and SPECT-CT image (C) show focal increased uptake over the lateral calcaneus, indicating peroneal tendonitis. Lateral calcaneal exostosis shown on CT (C) is likely related to long standing tenosynovitis.

as corticosteroid injection increases the risk of plantar fascia rupture.

Achilles tendon injuries

Achilles tendon injuries account for approximately 7% of running injuries and occur more commonly in males [3]. It also affects predominantly runners with many years of experience [3]. Runners with a forefoot strike have increased load in the Achilles tendon, increasing the risk of injuries [27]. The term “Achilles tendinitis” is often used to describe posterior heel pain; however it should be avoided as it implies an underlying inflammatory process within the tendon, which is not always the cause of pain [28]. In fact, two thirds of Achilles tendon injuries are actually paratenonitis and one fifth are bursitis and insertion tendinitis. The remaining Achilles tendon injuries are myotendineal junction injuries and tendinopathies [29]. Runners with paratenonitis complain of tolerable stiffness and pain aggravated by activity that is frequently worse at the beginning of their run. Runners with insertion tendinitis typically complain of focal pain at the insertion site of the Achilles tendon, worse after exercise [28]. On three-phase bone scan, Achilles tendinopathy and paratenonitis demonstrate increased blood flow and uptake on blood pool images. Insertion tendinitis of the Achilles tendon will show increased uptake at the insertion site at the calcaneus (**Figure 2**) [13]. Although bone scintigraphy will easily demonstrate insertion tendinitis, MRI represents a better imaging modality for Achilles tendon injuries given that these lesions can affect any part of the tendon.

Tibialis posterior injury

The tibialis posterior muscle originates from the interosseous membrane and adjacent tibia and fibula in the proximal third of the leg. The tibialis posterior tendon arises in the distal third of the leg, passes behind the medial malleolus to insert at multiple sites in the foot, including the navicular, cuneiforms and second, third and fourth metatarsals. Posterior tibial tendon dysfunction (PTTD) typically occurs in the elderly with connective tissue disease but can also affect younger patients with

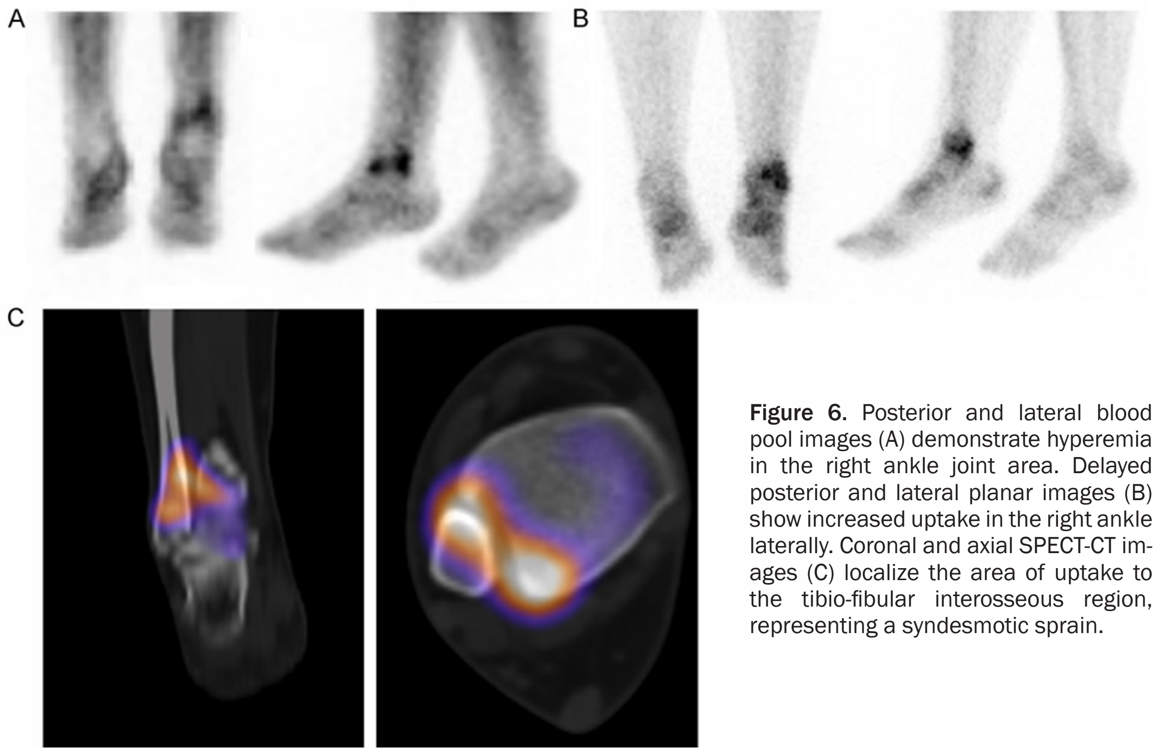


Figure 6. Posterior and lateral blood pool images (A) demonstrate hyperemia in the right ankle joint area. Delayed posterior and lateral planar images (B) show increased uptake in the right ankle laterally. Coronal and axial SPECT-CT images (C) localize the area of uptake to the tibio-fibular interosseous region, representing a syndesmotic sprain.

history of repetitive and high stress activity including running [30].

Three stages of PTTD have been described [31]. The early stage of PTTD is characterised by pain and swelling over the course of the tendon at the level of the medial malleolus and navicular insertion [32]. In runners, PTTD is an overuse injury caused by repetitive trauma leading to microtears, inducing an inflammatory response [30]. Early diagnosis of PTTD is important as unattended PTTD can lead to increase foot pronation, in turn placing greater strain on the posterior tibialis and worsening of PTTD [33]. This vicious circle can ultimately lead to loss of longitudinal arch and subsequent foot deformity of hindfoot valgus and forefoot abduction [30]. The literature on bone scan findings in PTTD is limited. On flow and pool images, increased uptake is seen along the tendon course and medial malleolus region, with increased uptake at the medial malleolus and navicular (**Figure 3**) [13, 34]. Malleolar uptake has been attributed to an adjacent inflammatory process and periostitis [34].

Sesamoid injuries

The sesamoid bones of the first MTP are located within the tendon of the flexor hallucis brevis, at the first metatarsal head. Sesamoid bones are usually paired and comprise the tibial (medial) and the fibular (lateral) sesamoid, with the tibial sesamoid bearing the majority of the weight [35]. They serve to increase the lever arm for flexion of the MTP joint [36]. Sesamoids are prone to injury with overuse, especially in repetitive high impact sports such as running [36]. There are several causes of sesamoid bone pain, including stress fracture (40%), sesamoitidis (30%), acute fracture (10%), osteochondritis (10%), osteoarthritis (5%) and bursitis (5%) [35]. Sesamoiditis, defined as inflammation of the surrounding structures of the sesamoids, is a diagnosis of exclusion [37]. Runners with sesamoid pathology usually present with vague long standing metatarsal pain, exacerbated by passive dorsiflexion of the MTP joint. Bone scan alone is sensitive for detection of sesamoid pathology but are incapable to distinguish between the various etiologies mentioned above [36]. Bone scan will demonstrate increased uptake on delayed imaging in cases of acute fracture, stress fracture, osteochondritis and sesamoiditis (**Figure 4**) [38]. Therefore, correlation with clinical history and radiographic findings, if available, can help distinguish between different causes of pain. Furthermore, the addition of SPECT-CT may provide additional informa-

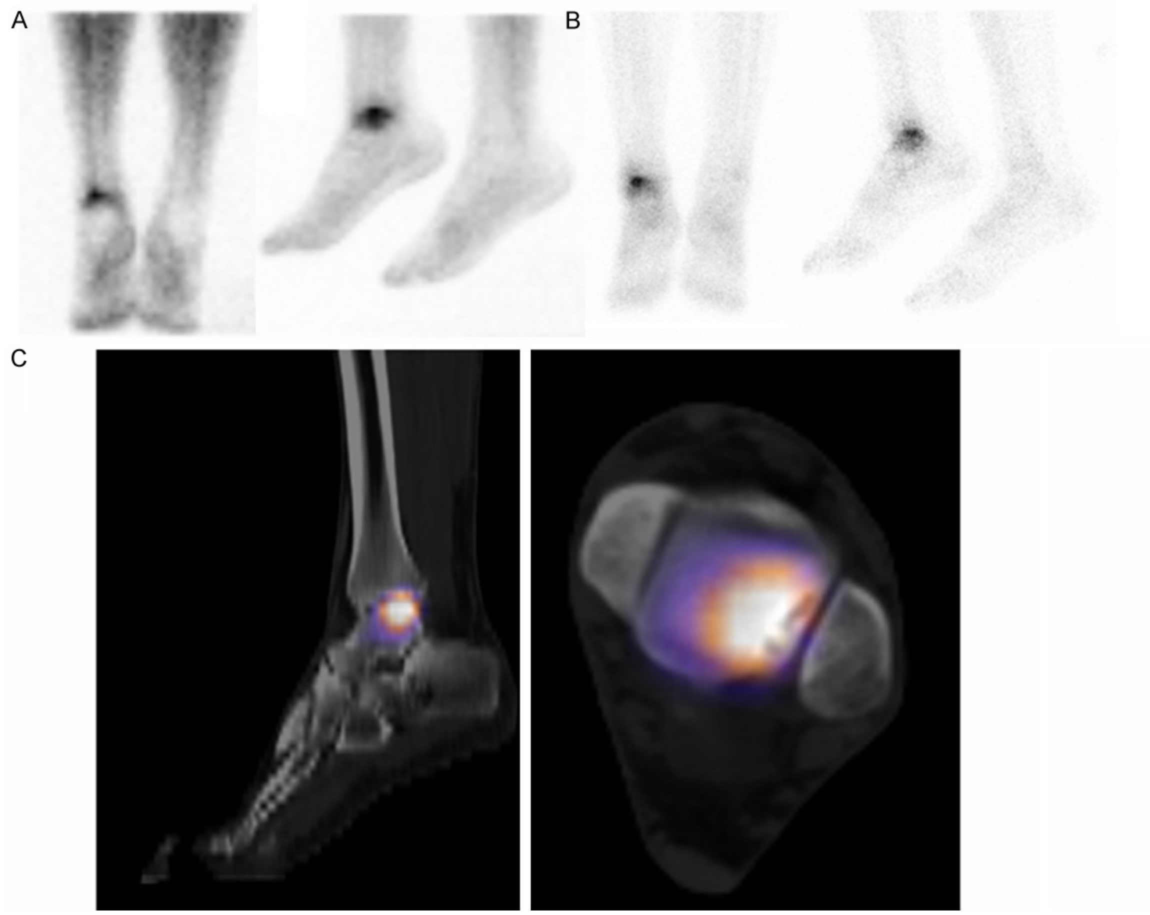
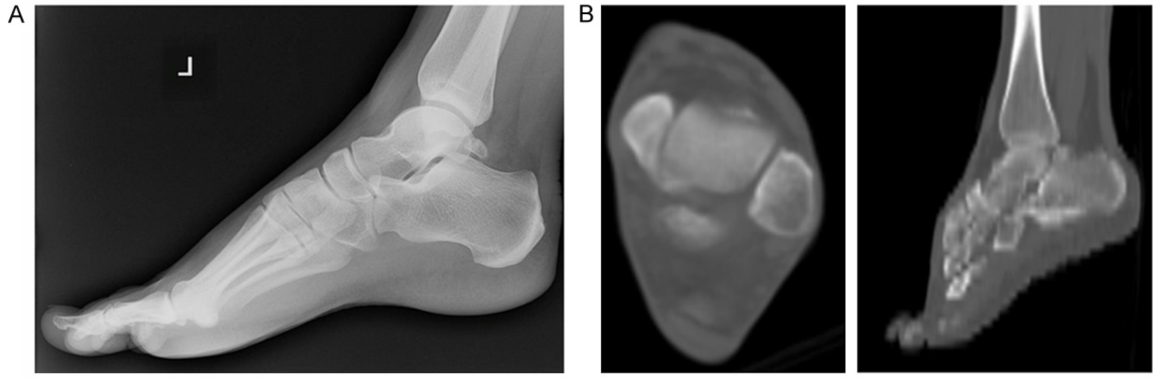


Figure 7. Posterior and lateral blood pool images (A) demonstrate hyperemia in the left ankle joint area. Delayed posterior and lateral (B) images show a similar distribution of activity. Sagittal and axial SPECT-CT images (C) localize the area of uptake in the subarticular region and talar dome, consistent with talar osteochondral lesion.

tion. Indeed, uptake in an intact sesamoid bone excludes a fracture whereas the presence of a fracture line on the CT with increased uptake on the bone scan favors an acute fracture. Bone scan can also be used to differentiate between multipartite sesamoid bones and sesamoid fractures. Treatment usually consists of rest and NSAIDs. Corticosteroids injection can also be considered. Sesamoidectomy is occasionally necessary in refractory cases [39-41].

Peroneal tendonitis

The peroneal brevis and peroneal longus muscles originate from the lower two thirds of the fibula. The peroneal tendons are located posterior to the fibula and act as abductors and evertors of the foot. The peroneal longus tendon passes below the trochlear process of the calcaneus and runs under the long plantar ligament to insert distally at the base of the first metatarsal base and cuneiforms. The peroneal brevis tendon inserts distally at the styloid process of the fifth metatarsal. Peroneal tendonitis is an overuse injury that can present as pain over the lateral calcaneus [28]. Because they often present as vague ankle pain, injuries of the peroneal tendons are thought to be underdiagnosed [42, 43]. Peroneal tendons injuries should be considered in all patients with chronic lateral ankle pain [44], especially in athletes as they have higher prevalence of the disease [45]. On three-phase bone scan, peroneal tendonitis presents as a curvilinear band of increased activity on blood flow and blood pool images [46]. Delayed images can demonstrate associated enthesopathy (**Figure 5**). Referral to an orthopedic surgeon is justified in cases of refractory ankle sprains with anterior talo-fibular ligament tears, calcaneo-fibular ligament and posterior talo-fibular ligament tears, as secondary chronic peroneal tendon instability might require surgical repair [47].



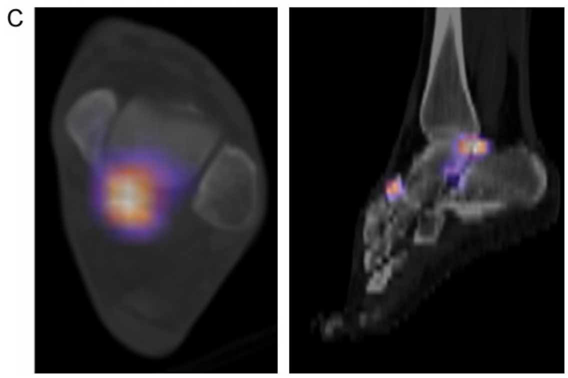
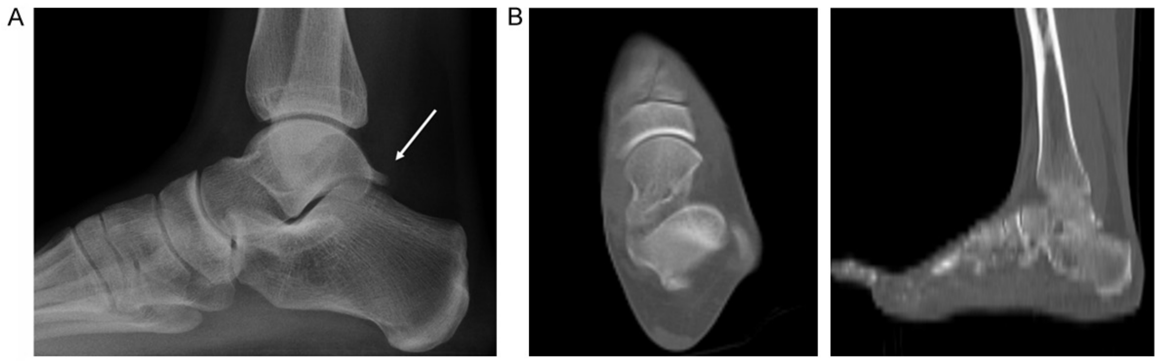


Figure 8. Lateral x-ray of the left ankle (A) shows well-corticated ossicle located posteriorly to the talus, consistent with an os trigonum. Sagittal and axial CT images (B) with corresponding sagittal and axial SPECT-CT images (C) of the left ankle show focal increased uptake in the os trigonum, consistent with os trigonum syndrome.



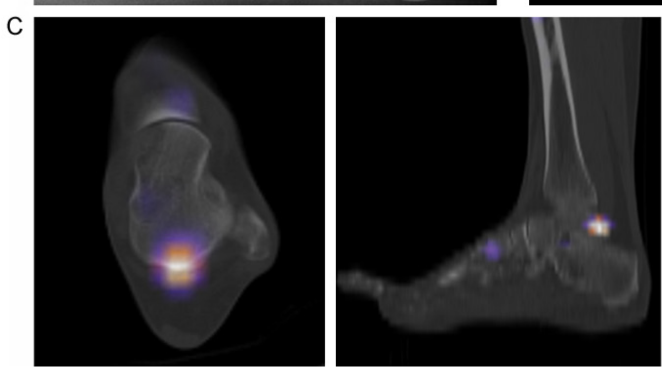


Figure 9. Sagittal and axial CT images (B) of the left ankle with corresponding SPECT-CT images (C) show focal increased activity in an ossicle located posteriorly to the talus. Review of lateral left ankle plain film (A) acquired 2 years before the bone scintigraphy shows a Stieda process (arrow). These findings are in keeping with a fractured Stieda process.

Ankle inversion injuries

Ankle sprains are the most common injuries in sports, representing 40% of all injuries [48]. Sprains affect athletes practicing sports involving lateral and stop-and-go motion including football, tennis, and basket-ball [49]. Nevertheless, ankle sprains represent approximately 1% of running related injuries [3]. The majority of ankle sprains occur on the lateral side and correspond to an ankle inversion injury. Running speed, cardiorespiratory endurance, balance, dorsiflexion strength, coordination, and range of motion of the ankle have been associated with increased risk of ankle inversion sprains [50]. Between 25% to 50% of patients will experience persistent ankle pain years after the initial injury [49, 51]. Causes of prolonged pain include talar osteochondral lesion (OCL), undetected syndesmotic sprain, and stress fractures [52], all of which can be detected on three-phase bone scan. Syndesmotic sprain are not easily identifiable on x-rays and CT, relying on widening of the space between the tibia and the fibula, a finding not always present in cases of tibio-fibular ligaments injury [53]. MRI can visualize the tendon and present several secondary findings [54]. However, MRI is not always performed in cases of unexplained chronic pain and these patients are often referred for a bone scintigraphy. Typically, bone scintigraphy will demonstrates increased ankle uptake on delayed images, especially in the posterior tibial region and interosseous membrane (**Figure 6**) [55]. Talar osteochondral lesion (OCL) most frequently involve the talar dome, medially or laterally [56]. On bone scan, these lesions are characterized by increased subarticular uptake that can also involve the entire posterior half of the talus (**Figure 7**) [57]. Bone scintigraphy is extremely sensitive for the diagnosis of talar OCL and can be used as a screening test in patients with chronic ankle pain, post inversion injury [58].

Posterior ankle impingement syndrome

Although classically described in ballet dancers, posterior ankle impingement (PAI) syndrome is not a rare cause of ankle pain in runners, accounting for approximately 15% of ankle injuries [59]. In particular, repetitive stress associated with downhill running has been shown to be associated with PAI [59]. Patients with this condition typically present with posterolateral ankle pain exacerbated by plantar flexion [60]. Predisposing factors include a prominent lateral talar tubercle (Stieda process), os trigonum, or any abnormal ossification in the posterior ankle; however, none of these features are pathognomonic as they are routinely seen on radiographs of asymptomatic patients. For example, an os trigonum is generally a clinically insignificant finding and present in 7% of the population [61].

Combining SPECT bone scintigraphy with CT makes it possible to correlate anatomical information with bone scan findings and results in a more accurate study than a bone scan or CT alone. For example, in the appropriate clinical context, the presence of an os trigonum on CT with increased uptake on bone scintigraphy is diagnostic of os trigonum syndrome (**Figure 8**) [62]. On bone scintigraphy alone, a fractured Stieda process can appear indistinguishable from an os trigonum, and can easily be an insignificant finding on conventional CT. SPECT-CT allows the physician to confidently differentiate this entity from os trigonum syndrome (**Figure 9**).

Conclusion

This article reviewed the mechanisms, clinical presentations, and SPECT-CT imaging patterns of different running injuries of the foot and ankle. A better understanding of the imaging patterns, as well as detailed information of the injury mechanisms being investigated, is essential in the evaluation of sports injuries. Indeed, this knowledge can increase a readers' confidence in establishing a more specific diagnostic and, ultimately, leads to a more useful report for the referring clinicians. Although MRI is now the modality of choice for these injuries, bone scintigraphy, with or without SPECT-CT, still plays an important role when the MRI findings are equivocal or out of keeping with the clinical presentation; However, this can create a referral bias where only patients with complicated presentations are being imaged, which reinforces the need for greater knowledge of these pathologies and the associated imaging findings. The addition of SPECT-CT to three-phase bone scintigraphy can improve localization and characterization of bone pathologies, ultimately resulting in an increase in diagnostic accuracy.

Disclosure of conflict of interest

None.

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