

# THE ROLE OF IMAGING IN TIBIA STRESS INJURY

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Stress fractures are frequently encountered injuries in the discipline of sports medicine, accounting for between 1 and 20% of all visits to the sports medicine clinic<sup>1</sup>. Tibial stress fractures account for half of all stress fractures and are especially common in athletes who are involved in repetitive impact sports that are often of high intensity<sup>1</sup>. Runners and younger participants in jumping sports are particularly prone to these injuries due to repetitive submaximal stress on the posterior medial cortex of the tibia. Stress fractures often occur after a change in training regime, surface or footwear. They can be disabling and result in a prolonged period away from active involvement, while the recurrence rate is 60%, highlighting the importance of getting an accurate diagnosis of the severity and of appropriate therapy<sup>1,2</sup>. The use of imaging to visibly demonstrate early stress lesions can be helpful in convincing athletes to seek

immediate rehabilitation, rather than to persist through the pain.

The differential diagnosis between shin splints – also known as medial tibial stress syndrome (MTSS) – and a true stress fracture is often difficult. MTSS can be thought of as a less advanced version of tibial stress fracture, involving pain at the posterior medial border during exercise with diffuse periostitis, but no cortical break<sup>2</sup>. The term stress fracture is therefore not an appropriate label for all stress injuries, as many do not show discontinuity of bone<sup>3</sup>. Instead MTSS can be seen as the first stage in the continuum of stress reaction, which may progress to the more severe stress fracture or frank cortical break. Nuclear medicine bone scans (NMBS) can be used to differentiate between MTSS and stress fractures (Figure 1).

Stress fractures are known as fatigue fractures and occur when abnormal stress occurs in bone with normal mineralisation.

In contrast, an insufficiency fracture occurs when normal stress acts on an already abnormal, usually osteoporotic bone. Tibial stress fractures are bilateral in 16% of cases and typically occur at the junction of the middle and distal third in adults<sup>1</sup>. Variants in tibial stress fractures include the anterior mid-diaphysis known as the ‘dreaded black line’ (transverse fracture line across entire shaft of the tibia) (see Figure 2) found in 5% of cases, and longitudinal stress fractures found usually in the mid- to distal bone<sup>1</sup>.

Diagnostic imaging is not routinely needed to diagnose stress fractures, as this determination is frequently made clinically. However, imaging has the ability to help confirm the diagnosis and determine the severity of the stress reaction, which assists in making the appropriate decisions for the rehabilitation process. Early intervention is the best policy, as it decreases the time until return to play (RTP) and imaging can

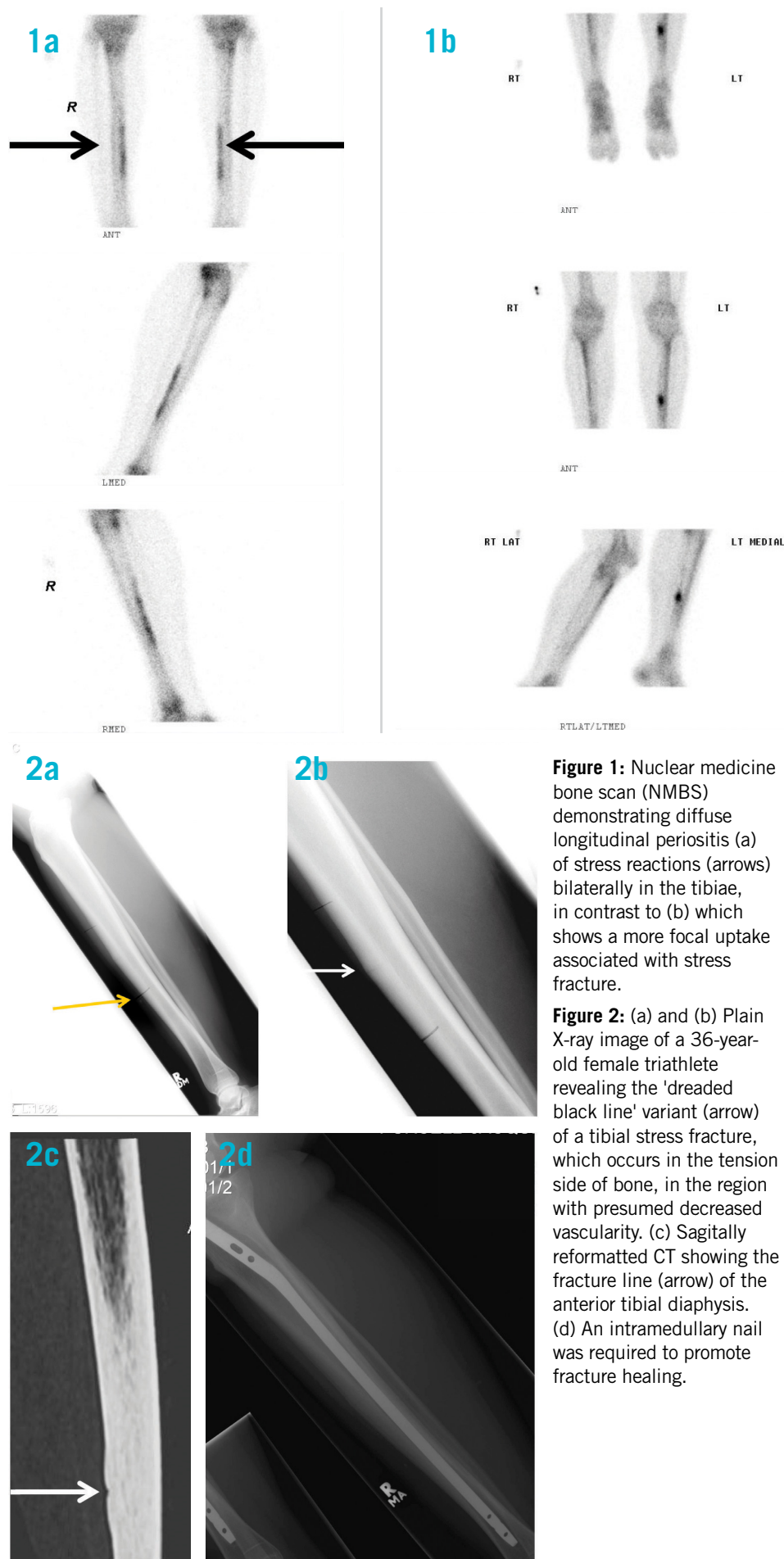
give a visible baseline representation of the lesions<sup>4</sup>. When required, MRI is the modality of choice for imaging of stress reactions, as it has the highest specificity and sensitivity and can detect early signs of stress reaction.

#### MECHANISM

The pathophysiology of a stress fracture involves the process of accelerated bony remodelling in response to chronic repetition of submaximal stress on healthy bone<sup>2</sup>. If the osteoblastic new bone formation is continuously exceeded by osteoclastic activity, the bone temporarily weakens. If the activity continues, trabecular micro-fractures occur, along with periosteal and bone marrow oedema which may eventually progress into a stress fracture or cortical break. Muscular fatigue can result in increased load due to periosteal forces from the muscle<sup>2</sup>. Stress injuries involving the tibial posterior medial cortex are common as this region is subject to compressive forces during running due to posterior muscle contractions<sup>4</sup>. The accelerated intra-cortical remodelling causes microscopic cracks, osteopenia and formation of resorption cavities<sup>5</sup>. The spectrum of injury, from normal bone to a stress fracture, is a continuum. Early stages of stress reaction often start with visible periosteal oedema, then bone marrow oedema and progress to visible fracture lines<sup>3</sup>.

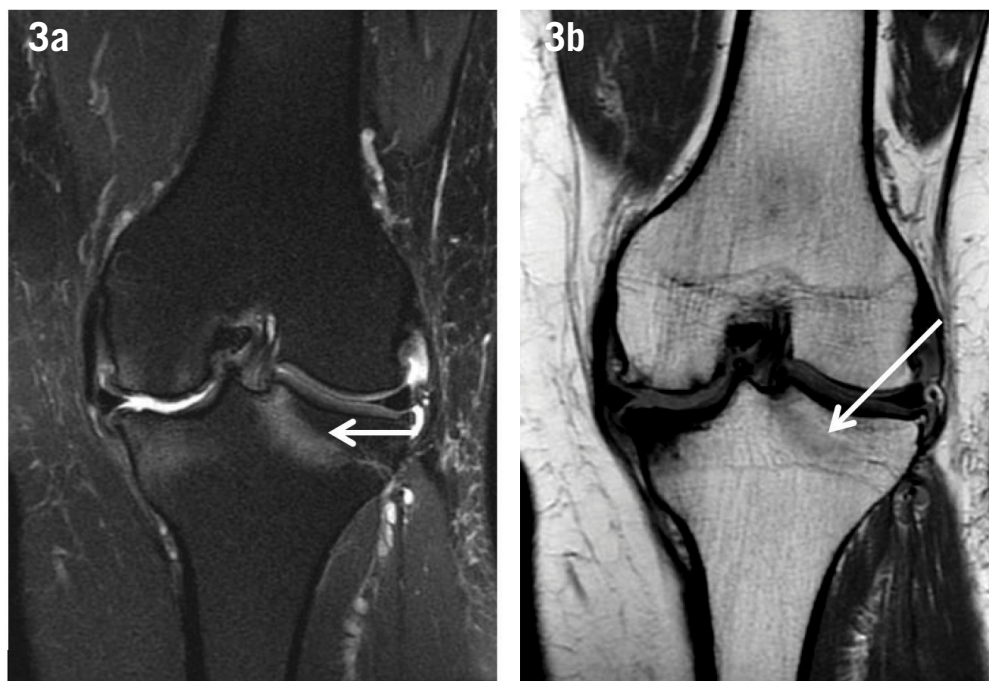
#### RISK FACTORS

Common intrinsic risk factors for stress fractures include anatomic and alignment predisposition, thinner long bone cortex and muscle weakness. Extrinsic risk factors include change in training regime or surface and increased volume or increased intensity of activity. Furthermore, inadequate shoes or equipment as well as inadequate rest and recovery between training sessions are important etiological factors. Failure to follow intensive training with recovery gives an inadequate amount of time for bone repair<sup>2</sup>. Running, especially long distances (one study suggests a benchmark of over approximately 32 km/week) was found to be associated with increased injury rate as well as jumping sports in



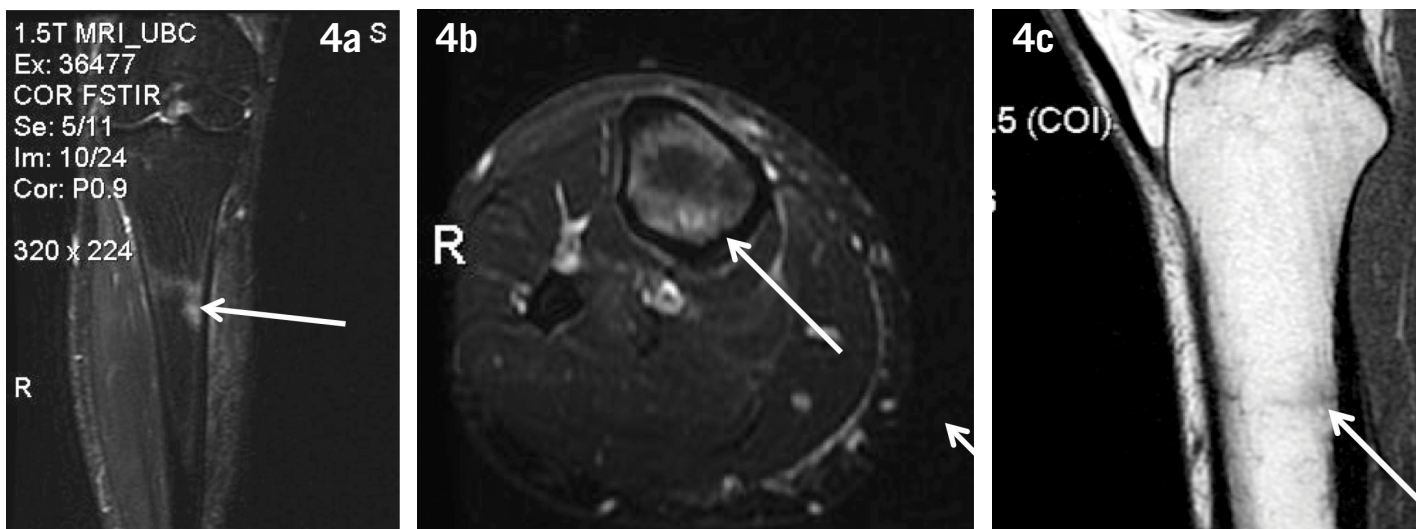
**Figure 1:** Nuclear medicine bone scan (NMBS) demonstrating diffuse longitudinal periostitis (a) of stress reactions (arrows) bilaterally in the tibiae, in contrast to (b) which shows a more focal uptake associated with stress fracture.

**Figure 2:** (a) and (b) Plain X-ray image of a 36-year-old female triathlete revealing the 'dreaded black line' variant (arrow) of a tibial stress fracture, which occurs in the tension side of bone, in the region with presumed decreased vascularity. (c) Sagittally reformatted CT showing the fracture line (arrow) of the anterior tibial diaphysis. (d) An intramedullary nail was required to promote fracture healing.



**Figure 3:** Fifty-three-year-old masters track athlete. Figure (a) is a fat-suppressed T2-weighted image showing high signal from bone marrow oedema indicating a micro-trabecular fracture (arrow), superimposed on tibio-femoral osteoarthritis. Figure (b) is a T1-weighted image and shows patchy non-discrete medullary decreased signal (arrow) indicating no cortical break.

**Figure 4:** MR images of a 43-year-old competitive walker with a Grade 4 stress fracture. Figures (a) and (b) demonstrate bright signal indicating bone marrow oedema in the sagittal and axial planes of a T2-weighted fat-suppressed sequence. Figure (c) shows a discrete low signal line extending to the cortex, indicating a stress fracture.



younger participants<sup>3</sup>. The 'dreaded black line' (anterior mid-diaphyseal tibial stress fracture) most often occurs in athletes involved in running and jumping sports<sup>2</sup>. These lesions can be particularly difficult to treat, as discussed below, which is likely due to the decreased vascularity of the anterior tibial cortex at the mid-diaphysis.

A study by Bennell et al found that female runners with stress fractures had a lower calf girth or less lean muscle mass<sup>6</sup>. Another study found that a cohort with stress fractures was found to have tibiae with significantly smaller cross sectional area compared to controls<sup>7</sup>. Furthermore, repetitive loading by runners in a single plane has been found to lead to asymmetrical geometry in comparison to soccer players.

Soccer players load in multiple directions and were found to have more robust and symmetrical bony geometry<sup>8</sup>.

#### HISTORY/PHYSICAL EXAM

The work-up with all patients should start with a thorough history and physical examination. The history is critical in determining any changes in the patient's workout regime and the frequency, location and pattern of pain. Typically, pain is not present at the start of activity but occurs after or towards the end of exercise, in contrast to musculoskeletal soft tissue injuries, where pain is experienced first thing in the morning and is relieved during activity. Pain arising from untreated stress reactions will begin to occur earlier in

training and linger longer with continued training, eventually persisting into daily activities. The history may reveal changes in footwear, running surfaces and other factors in the preceding 2 to 6 weeks. This information is crucial as any changes provide an opportunity for intervention. The physical exam should reveal prominent localised bony tenderness<sup>4</sup>, typically in the posterior medial tibial region and less commonly, swelling. In MTSS, more diffuse bony tenderness is experienced but it is often difficult to distinguish from the more focal tenderness of a stress fracture. Pain may be accentuated when testing the active contraction of muscles that have origins in the posterior medial tibia (soleus, posterior tibialis). Other clinical tests involve



identifying subtalar over-pronation<sup>2</sup> and using ultrasonography to evaluate muscles and tendons to exclude other etiologies for the pain<sup>5</sup>.

## IMAGING OPTIONS

### Magnetic resonance imaging

If imaging is required after a thorough history and physical exam, plain radiographs are often first obtained, but MRI is the imaging modality of choice in the assessment of tibia stress fractures<sup>2,4,5</sup>. MRI has multi-planar capability and excellent contrast resolution, giving it a high sensitivity for pathology and allowing it to precisely define the location and extent of the injury. Early intervention is possible as signal changes occur early in the course of the injury<sup>3</sup>. Techniques such as fat-suppressed T2-weighted and T1-weighted imaging are used to detect a spectrum of bony changes from initial periosteal oedema to more severe changes of bone marrow oedema that are useful ancillary markers for demonstrating the severity of the stress reaction<sup>5</sup> (Figure 3). MRI is found to be the most specific and sensitive modality (88%), in comparison to computed tomography (CT) and nuclear medicine

bone scan (NMBS) in the assessment of stress injury<sup>5</sup>. A study by Beck et al showed that clinical severity was predicted by MRI not CT, NMBS or plain radiographs<sup>9</sup> and that there was a positive trend between MR findings and the time to healing<sup>9</sup>. However, a study by Bergman et al performed on 21 asymptomatic college runners found that even though 43% of participants showed signs of tibial stress reaction on MRI, none of them developed a true stress fracture in the following 12 to 48 months. These findings underscore the importance of correlating MRI finding with clinical findings before making therapeutic decisions<sup>10</sup>.

An MRI classification system for tibial stress injuries was developed by Fredericson et al, based on the severity of periosteal oedema, bone marrow oedema and intra-cortical abnormality<sup>3</sup>. A grade 1 injury is defined as periosteal oedema, with high signal intensity changes along the cortical surface of the tibia on T2-weighted images<sup>6</sup>. Grade 2 is defined as both periosteal and bone marrow oedema (indicating cancellous microfractures), whereas grade 3 also includes ill-defined low signal on T1-weighted images in the medullary canal (more severe microfracture). A grade 4 stress

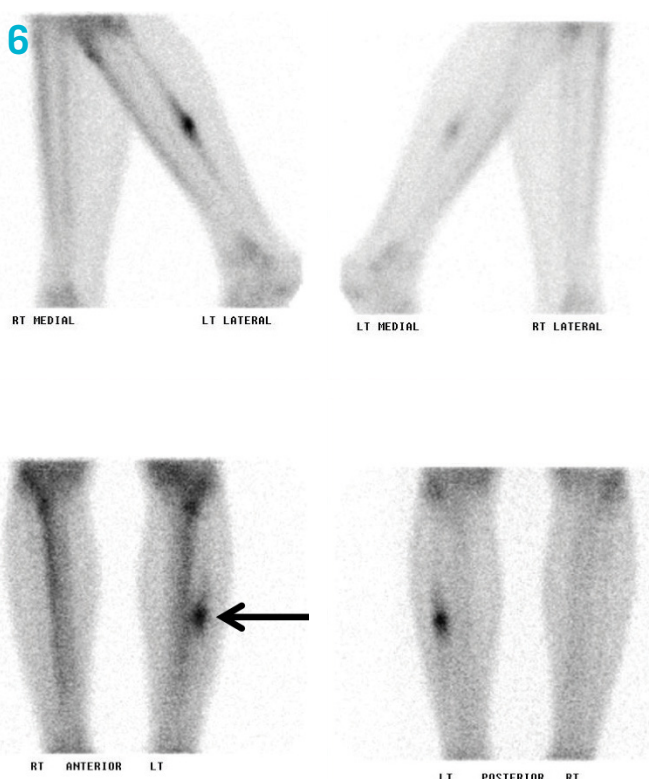
injury includes a visible fracture line, often best seen on T1-weighted images, denoting a true stress fracture<sup>3</sup> (Figure 4).

### Radiographs

Although frequently performed to exclude other etiologies for tibial pain, radiographs are often not positive for stress fracture until approximately 2 to 8 weeks after symptoms appear. Two-thirds of all initial radiographs of a group of symptomatic patients were found to be negative<sup>3</sup>. Radiographic sensitivity has been found as low as 10% in early stages, rising to between 30 and 70% sensitivity with follow-up studies (Figure 5). Typically visible on a radiograph is focal periosteal reaction. A 'gray cortex sign' is rarely seen, but denotes an area of decreased density due to focal hyperaemia, oedema and early calcium resorption<sup>11</sup>. However, early phases of bone stress injury verified with MRI were not reliably seen on radiographs<sup>5</sup>. Therefore, normal radiographs do not exclude a stress fracture.

### Nuclear medicine bone scans

NMBS are a highly sensitive modality, but lack specificity and cannot reliably show



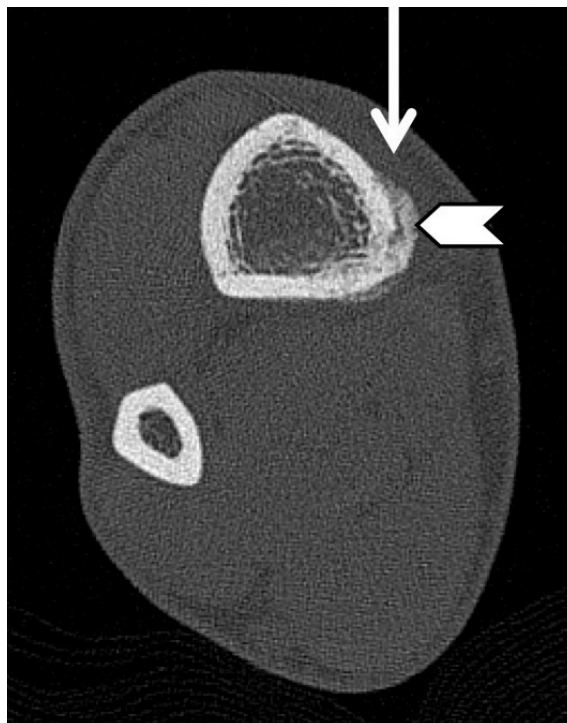
**Figure 5:** X-ray of the mid-diaphysis of the tibia in a 20-year-old triathlete. Plain radiographs have sensitivity as low as 10% in early stages and then 30 to 70% at follow-up. Typical findings of stress injury include periosteal reaction (arrow).

**Figure 6:** Delayed phase of NMBS demonstrating the focal intense uptake of radiotracer typical of a stress fracture (arrow), in this case of the fibula. NMBS=nuclear medicine bone scan.

fracture lines<sup>2</sup>. When positive for stress fracture, images show focal uptake in the cortical/trabecular region and images are positive 2 to 8 days after symptoms for all 3 phases (perfusion, blood pool and delayed) (Figure 6). MTSS can visibly be differentiated from stress fractures using NMBS. The periostitis in MTSS has longitudinal moderate uptake of radiotracer, whereas stress fractures have higher intensity uptake that is more focal. NMBS is also positive in infections, tumours and infarcts thereby making it hard to accurately differentiate disease processes requiring markedly different treatment. Although NMBS are uncommonly falsely negative, one study found false negative findings in eight proximal tibial stress injuries, out of a sample size of 50 patients that were later demonstrated by CT and MRI<sup>5</sup>.

#### Computed tomography

CT can add specificity over NMBS by showing periosteal reaction and the fracture line, the demonstration of which can be further optimised by multi-planar reformatting (Figure 7). CT is the modality of choice for imaging the 'dreaded black line' that is found in the tension side of the tibia in a region of presumed reduced vascularity (see Figure 2c). CT can detect subtle fracture lines and therefore can discriminate



**Figure 7:** Axial CT image showing a stress fracture (arrow) and periosteal reaction (arrowhead) in a 40-year-old half marathon runner.

between stress reaction and fracture. It is especially useful in the imaging of high-risk stress fractures of the femoral neck, tarsal navicular and anterior tibial cortex, which often require more aggressive treatment<sup>2</sup>. It also aids in distinguishing conditions that mimic stress fractures, such as osteoid osteoma, Brodie's abscess and tibia stress fracture variants (e.g. longitudinal). However, the sensitivity of MRI (88%) has been found to be higher in comparison to CT (42%) making it the modality of choice<sup>5</sup>.

#### ROLE OF IMAGING

Imaging plays an important role in return to sport through aiding in the specific diagnosis of a tibial stress injury and providing information about its severity, which assists clinicians in prescribing appropriate rehabilitation<sup>3</sup>. Early diagnosis is important for an optimised RTP. In a study by Fukushima et al it was found that patients younger than 20 years old who received imaging of their tibial stress injury within 3 weeks of onset of symptoms had a

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RTP of 10.4 weeks compared to 18.4 weeks for those who received imaging after 3 weeks<sup>13</sup>.

The Fredericson classification system allows a summary of multiple semi-quantitative MRI features of stress severity and can therefore help predict the optimal RTP for athletes with tibial stress injuries<sup>4</sup>. A study by Kijowski et al suggested that the MR classification system could be modified to distinguish only between grade 1 and grade 4b in relation to significant RTP difference. Grade 1 injuries had significantly shorter RTP (15.6 days) than other grades and grade 4b (linear), had significantly longer RTP (71 days) than other grades. There was no significant difference among grades 2, 3 and 4a in RTP<sup>4</sup>. Thus, the most important prognostic indicators of longer RTP are bone marrow oedema and linear signal changes<sup>4</sup>. The importance of correlating images with clinical knowledge are of course crucial in determining the severity and planning RTP.

#### TREATMENT

Prevention and early detection are the keys to the treatment of stress fractures. The temporary interruption of impact activity is crucial to allow for bony repair and remodelling<sup>4</sup>. The amount of time required for rehabilitation depends on the grade of the injury. Phase 1 of treatment includes pain control through rest (cross-training permitted), ice, massage, anti-inflammatory medicine and physical therapy modalities<sup>2</sup>. Weight-bearing is allowed for normal activities that lie within the tolerance of pain. Pneumatic braces are recommended for patients who cannot walk pain-free and may result in an earlier RTP. 'Dreaded black line' (anterior tibial diaphysis stress fracture) treatment options include excision, drilling and in severe cases of non-healing, insertion of an intramedullary rod (see Figure 2d). Phase 2 involves gradual return to sport once the athlete has been pain-free for 10 to 14 days, beginning with an initial training regime of decreased length and intensity.

#### CONCLUSION

Diagnostic imaging plays a role in confirming a clinically suspected diagnosis of stress injury and determining the extent of the stress reaction, while also excluding the possibility of other similar clinical entities. MRI is the modality of choice in

diagnosing stress fractures, as it most accurately identifies the severity of the stress reaction and helps with estimation of RTP. Imaging combined with a thorough history and physical exam can help lead to an early diagnosis. Proper diagnosis allows for a prompt return to activity through initiating immediate treatment and rehabilitation, in order to progress back into activity at full intensity.

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