Musculoskeletal stress injuries in athletes: A pictorial review

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Overview
In today’s world, professional athletics increasingly involves long hours of training with repetitive stressful movements of the musculoskeletal system, putting increasing levels of strain on the bones and their support apparatus and resulting in sports specific stress injuries. The prognosis of these injuries relies significantly on early recognition and appropriate management of athletes. The aim of this article is to familiarise radiologists and clinicians with the types of stress injuries and common site-specific radiological presentation of these injuries along with comparison of imaging modalities.

Pathophysiology of bone stress
Wolff’s law developed by Julius Wolff in the 19th century states that bone will adapt to resist forces acting upon it. Remodelling occurs and bone is deposited in sites subjected to increased load and resorbed in sites where there is reduced load. During normal training, muscles will strengthen rapidly and hypertrophy with increased activity. This relatively rapid response will be faster than the response of bone to increased stress. This delay in bone response and increasing muscle fatigue in training will place abnormal stresses on the bone which, due to the repetitive nature of many exercises, will focus stresses in particular areas of the skeleton. The increased load through a bone stimulated by increased activity overwhelms the repair capacity, producing microfractures leading to stress response and eventually stress fracture.

Fatigue fractures occur in normal healthy bone due to excessive stress not sufficient in itself to break the bone, but enough to cause trabecular microfracture. Excessive and repetitive muscular activity or force does not allow full recovery of the bone, resulting in progressive damage. Insufficiency fractures occur due to normal forces being applied to abnormally weak bone that has altered physical properties due to bone pathology, most commonly metabolic bone disease. In elite sports both fracture types can be combined as bone health can be an issue in athletes where reduced weight is an aid to performance.

Types of stress injuries
A stress response is the radiographic term for a bone stress injury without a demonstrable fracture. It is defined as an area of marrow oedema on MRI with or without periosteal reaction at a symptomatic site with no definite demonstrable fracture on cross-sectional CT or MR imaging. In the context of no specific episode of trauma and with an insidious onset of symptoms, a stress response is usually the precursor to a stress fracture.

A stress fracture is defined on MRI as marrow oedema and periosteal response with associated fracture line on MR/CT.

Distinction of stress fracture from stress response is necessary as, depending on the site and the athletic activity, the treatment and recovery times for each type of injury may well be significantly different.

Stress injuries: Incidence and risk factors
Stress injury represents 2% of all injury in athletes, 95% of which are in the lower extremity. Females are more at risk than males to bony stress injury, sometimes associated with the female athlete triad of eating disorder, amenorrhoea and reduced bone density. Caucasian, older age group and adolescent athletes have a higher incidence of stress injuries. Generally, stress injury is more common with muscle fatigue, or when there is a change in training intensity, especially in association with poor footwear.

Imaging modalities
Plain films are the first line investigation, but have low sensitivity (initial 15% and follow-up 56%). The initial x-ray can be normal in 25-40% of cases. Delayed films may show periosteal reaction, endosteal thickening and radiolucent dense black lines perpendicular to the trabeculae.

Scintigraphy, using Tc-99m bisphosphonates, demonstrates bone uptake in stress injuries with a sensitivity of almost 95% but has poor specificity. However, SPECT-CT plays an important role when the MRI findings are equivocal or out of keeping with the clinical presentation. SPECT-CT also sometimes has a role in management and rehabilitation planning.

MRI is the gold standard to assess bone stress injuries. In stress response there is an area of hyperintensity on the fluid sensitive sequences (FSS) but no fracture line demonstrated. As the injury evolves, there is further marrow oedema reducing the intensity of signal on the T1W images. These changes are accompanied by a periosteal reaction producing periosteal and endosteal increased signal on the FSS and eventually producing a linear hypointense fracture line. Gaeta and colleagues noted that MRI was more sensitive than scintigraphy and CT (sensitivity 86% for MRI, 74% for scintigraphy and 42% for CT) with a specificity of 100% for
both CT and MRL. CT has an important role and showed higher specificity (88%) than sensitivity (38%) in a large systematic review of imaging modalities for stress fractures by Wright and colleagues. CT is important in the evaluation of stress fractures of certain regions, particularly pars interarticularis, tibia, foot, and in clarifying longitudinal fractures. CT can identify periostitis, osteopaenia, cortical defects, and cortical bridging and is used as a problem-solving tool for evaluating equivocal lesions on MRI and scintigraphy. It is also useful for differentiating stress fractures from lesions, such as osteoid osteomas, by visualisation of the nidus.

Common site-specific injuries in athletes

The site of stress responses and stress fractures are sport specific, with a predominance in the lower extremity in running sports, soccer and cycling. Upper extremity stress fractures are uncommon and are reported in gymnasts and baseball pitchers. The spine, especially the pars interarticularis, is a site of stress fracture in many sports but particularly in cricket, soccer, gymnastics and tennis. Rib stress injuries are seen most commonly in rowers.

Lumbar spine stress injuries

Stress injuries in the lumbosacral spine are usually at the pars/pedicile junction. The incidence in the general population is between 3-6% but in elite sport in adolescence this rises to 40%. Frequently these are bilateral but they can be unilateral in 10-15% of cases. The injury is highlighted by prominent pedicular oedema on MRI in symptomatic athletes. Sometimes fractures can be seen but usually CT is performed to establish the balance between bony resorption and healing and to guide intervention for symptom control.

The aim of imaging is to firstly diagnose stress response prior to cortical disruption so that the fracture may be prevented and secondly to characterise the fracture and monitor progress allowing for appropriate intervention. The Hollenberg classification describes the progression of the pars/pedicile lesions on MRI. In this grading system, Grade 1 is a stress response with bone marrow oedema but no fracture, Grade 2 is an incomplete fracture involving one cortex, Grade 3 is a complete fracture across the bone; and Grade 4 is ununited defect with no bone marrow oedema. This classification is transferable to CT.

Pelvic stress injuries

Stress fractures of the pelvis account for 1.3-6% of stress fractures in athletes. Sacral stress fractures (figure 2) are most common in long distance runners, especially females, and are associated with the ‘female athlete triad’. In adolescent athletes it is important to consider lower lumbosacral pars interarticularis fractures. Fractures of the iliac crest apophysis are seen in adolescent athletes who are soccer players, gymnasts, runners and baseball players. Stress responses and pubic rami fractures are more common in footballers with an incidence of approximately 14-28%, are often seen in conjunction with adductor shear injuries and can form part of the spectrum of pubic overload/osteoitis pubis. Stress fractures of the pubic rami have a high rate of healing with adequate rest.

Femur/femoral neck stress injuries

Stress fractures of the femur account for approximately 4.2-7.2% of stress injuries in athletes and are more common in females. Stress injuries of the femora can occur in the neck or shaft. Fractures in the femoral neck can be tensile superolaterally or compressive inferomedially (figure 3). Femoral neck stress fractures tend to occur on the medial aspect at the junction of the proximal and mid thirds. Early diagnosis is essential to prevent the progression of stress responses to potentially career limiting fractures in athletes.

Tibial stress injuries

The tibia is the most common site for stress injury - most commonly shin splints or medial tibial stress syndrome (figure 4). This is characterised by localised pain occurring during exercise at the medial surface of the distal two thirds of the tibial shaft. Fredericson et al. developed a grading system which describes and stages stress injury by the MRI characteristics (table 1). Tibial stress fractures are most frequently transverse with about 10% longitudinal fractures. Posterior cortical fractures are seen in runners as a consequence of compression, and anterior cortical fractures in jumpers as a consequence of tension. Anterior fractures have a worse prognosis. CT is best at identifying intracortical fractures.

Fibula stress injuries

Fibula stress fractures represent approximately 1.3-12.1% of stress fractures in athletes. They are most common in the distal third of the fibula, proximal to the syndesmosis, are low risk and have good prognosis.

Tarsal stress injuries

Tarsal fractures account for up to 25% of stress injuries in athletes. Calcaneum is most commonly affected and typically presents with heel pain with stress fractures in the posterosuperior aspect of the calcaneum parallel to the posterior cortex (figure 5). Other sites can be affected including the medial tuberosity, posterosuperior calcaneum and the anterior process of the calcaneum.

Navicular stress injuries are most common in footballers in which they are a high risk injury. A high index of clinical suspicion is necessary and evaluation CT is essential to assess bony bridging, the extent across the navicular and the need for early internal fixation surgery. Navicular stress fractures are typically proximal, in the sagittal plane of the bone at the junction of the central and lateral thirds (figure 6), extend dorsal to plantar and may have a ‘Y’ shaped configuration. They have propensity for poor healing and non-union.

Metatarsal stress fractures occur frequently in runners, ballet dancers, gymnasts and soccer players. Initial x-rays can be normal with a periosteal reaction forming at four weeks. In runners, second and third metatarsal stress fractures predominate in the mid diaphysis or neck (figure 7). Ballet dancers have a predilection for the proximal second and third metatarsal bases. Football players most commonly sustain proximal fifth metatarsal fractures, in the metaphyseal region with a high incidence of non-union (figure 8). These fractures may benefit from internal fixation and early diagnosis and treatment is crucial. These should be distinguished from peroneus brevis avulsion fractures.

Rib stress injuries

Rib stress fractures are most commonly seen in rowers and, to a lesser extent, in golfers. The opposing actions of serratus anterior and external obliques contributes to shearing stress on the bony attachments of these muscles, resulting in rib stress response and fractures.

Upper limb stress injuries

Upper extremity stress fractures are uncommon and are reported in gymnasts, baseball pitchers, tennis and cricket players. Higher incidence of olecranon stress fractures in baseball players, and lunate fractures (low risk) in tennis players have been reported.

Summary

Bony stress injury is a common cause of lower limb overuse pain in all athletes. The aim of imaging is to identify stress reactions before fracture occurs and to employ grading systems to guide management and prognosis. Plain film is the initial modality but has poor sensitivity. MRI is the modality of choice if the radiograph is negative. CT is very specific and very useful for taking management decisions regarding prognosis and return to play. We hope that this review will help familiarise radiologists with the appearances of common stress injuries in athletes, along with appreciation of the
importance of stress response imaging on helping guide clinical management and prevent progression to career limiting fractures.

References
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29. Harrington T, Crichton K J, Anderson I P. Overtake ballet injury of the

TABLE 1
Fredericson grading system. (BMO = bone marrow oedema).

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<thead>
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<th>MRI grade</th>
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<tbody>
<tr>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>1</td>
<td>Increased periostal T2 signal; normal marrow signal</td>
</tr>
<tr>
<td>2</td>
<td>Grade 1 + BMO signal on T2W images</td>
</tr>
<tr>
<td>3</td>
<td>Grade 2 + BMO signal on T2W and T1W images</td>
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<tr>
<td>4</td>
<td>Grade 3 + clearly visible fracture</td>
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Figure 1
Left: T2-FS MR demonstrates hyperintensity within the pedicle of L5 with corresponding hypointensity on T1 MR image, consistent with marrow oedema (arrows). Cortical margins are intact. The appearance is consistent with an acute stress reaction. Right: Repeat images four months after conservative management show resolution of hyperintensity within the pedicle on T2-FS MR, consistent with healed stress injury. Note the small area of hyperintensity within the inferior margin of the pedicle on T1 MR, indicating development of a small area of fatty marrow replacement. This is a common finding following stress injury.31

Figure 2
Left: Coronal T2 FS MRI of the sacrum showing bone marrow oedema in the left sacrum with a fracture line (arrow). Right: Follow-up coronal T1 MRI demonstrating the fracture line (arrow) surrounded by fatty bone marrow.17
**Figure 3**
Left to right: Initial x-ray of the left hip shows faint sclerotic line in the left neck of femur. T1 MR shows abnormal low signal in the medial aspect of the left neck of femur, and the STIR MR shows high signal in the same region along with a hypointense fracture. X-ray one month later shows radiolucent dense black line perpendicular to the trabeculae, with surrounding sclerosis. (Images courtesy of Dr G Rajeswaran, Chelsea and Westminster Hospital, London, UK)

**Figure 4**
Left to right: Axial T1 and STIR MR images of left tibia showing marked periosteal and bone marrow oedema but no fracture line, with the x-ray demonstrating periosteal reaction in mid tibia. These appearances are in keeping with a Grade 2 medial tibial stress response. (Images courtesy of Dr G Rajeswaran)

**Figure 5**
STIR (left) and T1 (right) MRI of an athlete demonstrating high signal oedema on STIR with a hypointense fracture line (T1 and STIR) in the posterior superior aspect of calcaneus. (Images courtesy of Dr G Rajeswaran)
Figure 6
Sagittal T2 FS MRI demonstrating a sagitally oriented navicular stress fracture (arrow).27

Figure 7
Axial (left) and coronal (right) STIR images of MRI of the foot of an athlete, which demonstrate high signal in the bone marrow, periosteum and surrounding soft tissues of the third metatarsal, along with a linear low signal fracture line in the neck. The appearances are in keeping with a third metatarsal neck stress fracture. (Images courtesy of Dr G Rajeswaran)

Figure 8
Left: Oblique and AP x-rays of a soccer player with proximal fifth metatarsal fracture. Right: Healed fracture after internal screw fixation.30 Return to play is usually between six to eight and a half weeks.