Exercise-related lower leg pain: bone

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Bony pathology is a common cause of exercise-related lower leg pain. The two bony pathologies seen most frequently are stress fractures and the condition traditionally known as “shin splints” or “medial tibial stress syndrome” but more accurately described as traction periostitis of the posteromedial border of the tibia. Other bony pathologies seen occasionally include tumor and infection.

TRACTION PERIOSTITIS
The pathogenesis of traction periostitis has not been clearly defined. It is thought to arise from chronic traction on the periosteum at the periosteal-fascial junction (9). Chronic symptoms may occur from avulsion of the periosteum. Detmer (27) hypothesized that the periosteum becomes traumatically disengaged from the bone via ballistic avulsion or by subperiosteal bone stress on the tibial edge, resulting in sufficient subperiosteal hemorrhage or inflammation to lift the periosteum away from the bone. The soleus muscle is the most likely cause of these avulsions because it partially attaches medially into the investing fascia. Detmer consistently found adipose tissue between the periosteum and underlying bone in operative cases.

The patient with traction periostitis complains of pain along the medial border of the tibia, which usually decreases with warming up. The athlete can often complete the training session, but pain gradually recurs after exercise and is worse the following morning. On examination, there is commonly an area of maximal tenderness along the medial border of the tibia that may extend along the entire tibia or may be as little as 2 cm in length. This usually occurs at the junction of the lower third and upper two-thirds of the tibia. There may also be tenderness and induration within the fascia just posterior to the medial border. Excessive pronation is often present.
Plain x-ray shows no abnormality in this condition. Isotopic bone scan appearance may show patchy areas of increased uptake along the medial border of the tibia as shown in Figure 1. In the early stages, however, the bone scan appearance may be normal magnetic resonance imaging (MRI) is probably not helpful in diagnosing this condition other than ruling out stress fracture as the any changes seen are usually nonspecific.
Little scientific evidence exists regarding the effectiveness of the various treatment methods in this condition. Our clinical experience has shown the following regime to be effective.

Initial treatment is to reduce inflammation by the use of rest, NSAIDs, ice, and electrotherapeutic modalities. Podiatric assessment and advice regarding stretching and training are also important components of the management of this condition. The most effective definitive treatment involves deep massage therapy which should be applied to the thickened muscle fibers of the soleus, flexor digitorum longus, and tibialis posterior adjacent to their bony attachment, avoiding the site of periosteal attachment, which may prove too painful. Abnormalities of the tibialis posterior may be treated through the relaxed overlying muscles. Myofascial release can be applied parallel to the tibial border, releasing flexor digitorum longus, and along the soleus aponeurosis in the direction of normal stress with combined active ankle dorsiflexion.

Significant biomechanical abnormalities may need correction with orthotics. Training should recommence on alternate days only, wearing appropriate footwear and running on shock-absorbent surfaces. There is currently no evidence that surgery is helpful in this condition.

STRESS FRACTURES

The diagnosis of a stress fracture requires clinical experience, a detailed knowledge, and a precise musculoskeletal examination. In each case, there are three questions that need to be answered.

1. Is the pain of bony origin?
2. If so, which bone is involved?
3. At what stage in the continuum of bone stress is this injury?

To obtain an answer to these three questions requires a thorough history, detailed examination, and appropriate use of imaging techniques.

History

The history of the patient with stress fracture is typically one of gradual onset of activity-related pain. Initially, the pain will usually be described as a mild ache occurring with a specific amount of exercise. If the patient continues to exercise, the pain may well become more severe or occur at an earlier stage of exercise. The pain may increase to eventually limit the quality or quantity of the exercise performed or occasionally to force cessation of all activity. In the early stages, pain will usually cease soon after exercise. However, with continued exercise and increased severity of symptoms, the pain may persist after exercise. Night pain may occasionally occur. The pain is usually well localized to the site of the fracture.
As well as obtaining a history of the patient's pain and its relation to exercise, it is important to determine
the presence of predisposing factors (Table 1). Therefore, a training or activity history is essential. In
particular, note should be taken of recent changes in activity level such as increased quantity of training,
increased intensity of training, changes in surface, equipment (principally shoes), and technique. It may be
necessary to obtain training information from the patient's coach or trainer. A full dietary history should be
taken and particular attention should be paid to the possible presence of eating disorders. In female
subjects, a menstrual history should be taken, including age of menarche and subsequent menstrual status.

<table>
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<tr>
<th>Extrinsic Factors</th>
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<td>Training errors</td>
<td>Malalignment</td>
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<td>Excessive intensity</td>
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<td>Rapid increase</td>
<td>Rearfoot varus</td>
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<td>Sudden change</td>
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<td>Excessive fatigue</td>
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<td>Inadequate recovery</td>
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<td>Surfaces</td>
<td>Femoral neck anteversion</td>
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<td>Hard</td>
<td>Tibial torsion</td>
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<td>Soft</td>
<td>Leg length discrepancy</td>
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<td>Cambered</td>
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<td>Shoes</td>
<td>Muscle weakness</td>
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<td>Worn out</td>
<td>Generalized muscle tightness</td>
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<td>Equipment</td>
<td>Focal areas of muscle thickening</td>
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<td>Inappropriate</td>
<td>Restricted joint range of motion</td>
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<td>Psychological factors</td>
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<td>Inadequate nutrition</td>
<td>Sex, size, body composition</td>
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Table 1. Predisposing factors to overuse injuries.

A history of a previous similar injury or any other musculoskeletal injury should be obtained. A review of
systems should be obtained to assess the patient's general health, medications, and personal habits to
ensure that there are no factors that may influence bone health. It is also important to obtain from the
history an understanding of the patient's work and sporting commitments. In particular, it is important to
know at what level and how serious the patient is about his or her sport and what significant sporting
commitments are ahead in the short and medium term.

Physical Examination
On physical examination, the most obvious feature is localized bony tenderness, typically on the
postero-medial border of the lower third of the tibia. Occasionally, redness and swelling are present at the
site of the stress fracture. There may also be palpable periosteal thickening, especially in a longstanding
fracture. Percussion may result in the production of pain at a point distant from the percussion. Joint range
of motion is usually unaffected.

Some authors have suggested that the presence of pain when therapeutic ultrasound is applied over the
area of the stress fracture is of potential use in the detection of stress fractures (22, 26, 51). However, Boam
et al. (11) showed the sensitivity of ultrasound was only 43% in the detection of stress fractures compared
with isotope bone scan. They also had a high false-positive rate. Our own experience has not shown this
method to be particularly helpful. Similarly, it is reported that application of a vibrating tuning fork to the
affected bone and subsequent increase in pain is indicative of a stress fracture. We have also not found this
method to be particularly helpful.

The physical examination must also take into account the potential intrinsic predisposing factors and a full
biomechanical examination must be performed. Any evidence of leg length discrepancy, malalignment
(especially excessive subtalar pronation), muscle imbalance, weakness, or lack of flexibility should be
noted.

Imaging

Imaging plays an important role in supplementing clinical examination to determine the answers to the three
questions outlined at the start of this paper. In many cases, a clinical diagnosis of stress fracture is
sufficient. The classic history of exercise-associated bone pain and typical examination findings of localized
bony tenderness have a high correlation with the diagnosis of stress fracture. However, if the diagnosis is
uncertain, or in the case of the serious or elite athlete who wishes to continue training if at all possible and
requires more specific knowledge of his or her condition, there are various imaging techniques available to
the clinician. It is essential that the clinician uses the imaging results as an adjunct to the clinical features as
some of the imaging modalities used for stress fractures are extremely sensitive and may detect subtle
abnormalities that are not the cause of the patient’s symptoms.

Plain radiography.

Plain radiography is widely available and relatively inexpensive. It has poor sensitivity but high specificity in
the diagnosis of stress fractures. Unfortunately, in the majority of stress fractures, there is no obvious
radiographic abnormality. The abnormalities on radiography are unlikely to be seen unless symptoms have
been present for at least 2–3 wk. In many cases, they may not become evident for up to 3 months and in a
significant percentage of cases never become abnormal.

The initial manifestation of a stress fracture is a localized periosteal reaction (Fig. 2). After osteoclastic
resorption at the site of the stress fracture, a cortical lucency may then become apparent. During healing,
the linear stress fracture may undergo resorption around the margin, becoming an ovoid lucency within a
thickened area of cortical hyperostosis. Characteristically, the healing stress fracture will demonstrate thick
lamellar periosteal reaction on both the endosteal and periosteal surface confined to a focal area (57).
Figure 2 Plain radiograph showing periosteal reaction.
Plain radiography should be performed as the first line investigation in these sites.

**Isotopic bone scan (scintigraphy).**

If plain radiography demonstrates the presence of a stress fracture, then there is seldom any need to perform further investigations. However, in cases where there is a high index of suspicion of stress fracture and a negative bone radiograph, the triple-phase bone scan has traditionally been the next line of investigation. The bone scan is highly sensitive but has low specificity. Prather et al. (56) stated the bone scan had a true-positive rate of 100%, and false-negative scans are relatively rare (41,49).

In the appropriate clinical setting, the scintigraphic diagnosis of a stress fracture is defined as focal increased uptake in the third phase of the bone scan. The inclusion of the first and second phases of the bone scan permits the estimation of the age and severity of stress-induced focal bony lesions and helps to differentiate soft tissue inflammation from bony injury (63). As the bony lesion heals, the perfusion returns to normal first followed by normalization of the blood pool image a few weeks later. Focal increased uptake on the delayed scan resolves last because of ongoing bony remodeling and generally lags well behind the disappearance of pain. As healing continues, the intensity of the uptake diminishes gradually over a 3- to 6-month period after an uncomplicated stress fracture, with a minimal degree of uptake persisting for up to 10 months (2) or even longer.

The radionuclide scan may be positive as early as 7 h after bone injury (61). Matin (45) found that 95% of fractures in patients under 65 yr of age can be demonstrated in the first day and in 100% of patients by 3 d.

The disadvantage of bone scan is its lack of specificity in that the fracture itself is not visualized, and it may be difficult to precisely locate the site of the fracture, especially in the foot. Other nontraumatic lesions such as tumor (especially osteoid osteoma), osteomyelitis, bony infarct and bony dysplasias can also produce localized increased uptake. It is, therefore, vitally important to correlate the bone scan appearance with the clinical features.

The characteristic bone scan appearance of a stress fracture is that of a sharply marginated or fusiform area of increased uptake involving one cortex or occasionally extending the width of the bone (62) (Fig. 3).
MEDIAL RT TIBIA
The radionuclide scan will detect evolving stress fractures at the stage of accelerated remodelling. At that stage, which may be asymptomatic, the uptake is usually of mild intensity, progressing to more intense and better defined uptake as microfractures develop (62). Wilcox et al. (71) suggest that the pain associated with a stress fracture may not be present before the radionuclide scan becomes positive.

Increased radionuclide uptake is frequently found in asymptomatic sites (36,43,44,47). Originally, the presence of increased tracer uptake at nonpainful sites in athletes was interpreted as unrecognised stress fractures (24,60,62). Other authors postulated that there may be nonspecific stress changes related to bone remodelling (63), a false-positive finding (34), and an uncertain finding (19). Rosen et al. (60) found asymptomatic uptake in 46% of cases with focal uptake more common that diffuse uptake.

Matheson and his colleagues in Vancouver (44) proposed the concept of bone stain. They noted that radionuclide bone scan, because of its sensitivity, was able to demonstrate the adaptive changes in bone at any point in the continuum from early remodelling to stress fracture. The term bone strain was coined to reflect the true dynamic response of bone to stress and allow the interpretation of bone changes along the continuum to be correlated with the wide range of presentations seen in clinical practice. Excessive loading from overuse, abnormal biomechanics, reduced shock absorption, or altered gait produces a mechanical stress, which is translated into bone remodeling via piezoelectric stimuli. The relative contribution of these factors as well as the athlete’s activity pattern after the onset of remodeling determines the extent of bone strain seen clinically. Pain during activity may indicate small areas of remodeling, which have low-intensity uptake on bone scan and negative x-rays. On the other hand, pain that persists after exercise and during rest may indicate more extensive remodeling with intense uptake on scan and possibly abnormal radiographs.

This concept of a continuum of bone strain existing both clinically and scintigraphically is now widely accepted. It is now clear that bone stress can appear as an area of increased uptake on isotope bone scan before any symptoms occur. It is not clear what percentage of these cases progress to symptomatic bone stress and ultimately stress fracture if exercise is continued. It is also not clear what treatment is appropriate in these cases of asymptomatic bone stress. Many athletes and dancers in hard training show up numerous areas of bone stress on an isotope bone scan. These are indicators of active remodelling and are not necessarily bone at risk for the development of stress fracture.

Attempts have been made to classify the bony continuum into “bone strain” or “asymptomatic stress reaction” and stress fracture. A summary of these features may be seen in Table 2.

<table>
<thead>
<tr>
<th>Table 2. Continuum of bony changes with overuse.</th>
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<tr>
<td><strong>Local pain</strong></td>
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<td><strong>Local tenderness</strong></td>
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<td><strong>X-ray appearances</strong></td>
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<td><strong>Radiostic bone scan appearance</strong></td>
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Table 2. Continuum of bony changes with overuse.

A scheme for grading bone scan appearance on the basis of severity has been proposed by Zwas et al. (73) (Table 3). They found that minimally symptomatic stress fractures were grade 1 or 2 and that the resolution rate of the milder grades was higher with more complete healing. This grading system may assist in determining the rest and rehabilitation periods necessary.
Computerized tomography.

Computerized tomography (CT) is useful in differentiating those conditions with increased uptake on bone scan that may mimic stress fracture. These include osteoid osteoma, osteomyelitis with a Brodie’s abscess, and various malignancies.

CT scanning is also valuable in detecting fracture lines as evidence of stress fracture (Fig. 4) where plain radiography is normal and isotope bone scan shows increased uptake. CT scanning will enable the clinician to differentiate between a stress fracture, which will be visible on CT scan, and a stress reaction. Particularly in the elite athlete, this may considerably effect their rehabilitation program and their forthcoming competition program.
Figure 4 CT appearance of stress fracture of the tibia.

**Magnetic resonance imaging.**

MRI is being increasingly advocated as the investigation of choice for stress fractures. It has similar sensitivity to isotope bone scan and has the added advantage of excellent anatomical visualization. Unlike bone scan, it will differentiate between stress fracture and tumor as well as localizing the stress fracture.

MRI is performed on a variety of equipment; however, field strength should be 1.0–1.5 T. Total body scanners have been traditionally used although the recent advent of dedicated extremity scanners holds the promise of relatively low-cost evaluations. A combination of T1-weighted sequences that optimize anatomic detail and a sequence that depicts bone edema are required for assessment of bone stress injuries (28). A variety of edema-sensitive sequences are widely available and typically employ some form of fat suppression to further enhance contrast. Among the widely used edema sequences are short-time inversion recovery (STIR), newer faster STIR sequences, and fat-suppressed proton density and T2-weighted fast-spin echo sequences. Sequences are typically performed in multiple orthogonal planes (e.g., coronal, sagittal, and axial) and requirements differ depending on the region of interest (28). The earliest evidence of bone stress is the appearance of periosteal and/or marrow edema. This shows as an area of reduced signal on T1-weighted sequences and higher signal (brighter appearance) on T2-weighted sequences (Fig. 5). In the absence of clinical symptoms or signs, these areas should be considered the equivalent of the areas of increased uptake on bone scan that indicate early bone stress. In the presence of clinical evidence of bone injury and the absence of a fracture line, these appearances should be considered evidence of a stress reaction. These areas of edema have similar appearances to bone contusional injuries (bone bruises) as well as other less common conditions such as transient bone marrow edema syndrome, very early osteonecrosis (AVN), osteomyelitis, and infiltrative neoplasm. The findings must be carefully correlated with the clinical symptoms and signs to differentiate between the various diagnoses.
Figure 5 MRI showing periosteal and marrow edema in the absence of a fracture line.
Evidence of a stress fracture on MRI is the presence of a “fracture line” that appears as low signal on all sequences. The fracture line is continuous with the cortex and extends into the intramedullary space oriented perpendicular to the cortex and the major weightbearing trabeculae (28). The zone of surrounding edema within the medullary space can be very intensive, producing a large amount of abnormal signal loss in the marrow on T1-weighted images. The fracture line may itself be obscured on the T1-weighted images by the surrounding low signal edema. Proton density-weighted images with fat suppression are excellent for depiction of the fracture line and surrounding edema (39). On T2-weighted and STIR sequences, the fracture line remains low in signal intensity, and the surrounding marrow edema is seen as an amorphous region of increased signal (48) (Fig. 6). Increase in signal on the edema-sensitive sequences becomes less prominent with increasing duration of symptoms. High signal may not be present if the patient is imaged more than 4 wk after the onset of symptoms.
Arendt et al. (3) proposed a grading scheme for MRI appearances of stress fractures using short T1 inversion recovery images. This was further modified by Fredericson et al. (32), who used fat saturated images as the basis of the grading scheme. In this grading system, grade I indicated mild to moderate periosteal edema on T2-weighted images only with no focal bone marrow abnormality. Grade II showed more severe periosteal edema as well as bone marrow edema on T2-weighted images only. Grade III showed moderate to severe edema of both the periosteum and marrow on both T1 and T2-weighted images. Grade IV demonstrated a low signal fracture line on all sequences with changes of severe marrow edema on both T1- and T2-weighted images. Grade IV may also show severe periosteal and moderate muscle edema. Fredericson and his colleagues looked at runners with medial shin pain and compared the clinical findings, bone scan appearances, and MRI appearances. In 14 of 18 symptomatic legs described in this study, MRI findings correlated with the established bone scan grading system. They concluded that their grades I–IV were equivalent to the bone scan grading described by Zwas et al. (73) mentioned in the previous section. The comparison of grading of stress fractures between bone scan (73) and MRI (32) are shown in Table 3.

Yao et al. (72) examined the prognostic value of MRI in 35 patients with suspected stress fractures. An MR finding of a “fracture” or “fatigue” line or a cortical signal intensity abnormality was predictive of a longer symptomatic period, whereas muscle edema was predictive of a shorter symptomatic period. They did not find the grading system described above to correlate with clinical outcome.

Fredericson et al. (32) felt that the MRI more precisely defined the anatomic location and the extent of the injury. They also identified certain clinical symptoms, such as pain with daily ambulation, and physical examination findings including localized tibial tenderness and pain with direct percussion, that correlated with more severe grades of bony injuries, in this case, in the tibia. The authors recommended MRI over bone scan for grading of tibial stress lesions, stating that MRI is more accurate in correlating the degree of bone involvement with clinical symptoms. Additionally, bone images of MRI involve lack of exposure to ionizing radiation and significantly less imaging time than triple-phase bone scintigraphy. These authors suggest that periosteal edema represents the initial response of the tibia to nontraumatic, repetitive stress, and although it can occur in the anterolateral portion of the tibia, it often appears in the same location as most tibial stress fractures, at the posteromedial cortex.

**Bone scan or MRI?**

The decision to use isotope bone scan or MRI as the investigation of choice for stress fractures is not straightforward. In the vast majority of cases, the combination of clinical presentation, plain radiograph, and isotope bone scan is sufficient for a diagnosis of stress fracture. MRI is comparable in sensitivity to bone scan and has the added advantage of visualizing the fracture. However, MRI is considerably more expensive and this extra cost must be weighed against the added benefit.

**Treatment**

The actual time from diagnosis of a stress fracture to full return to sport depends on a number of factors including the site of the fracture, the length of the symptoms, and the severity of the lesion (stage in the spectrum of bone strain).

Most stress fractures of the tibia with a relatively brief history of symptoms will heal without complication or delay and permit return to sport within the 8- to 12-wk range.
Although there are many subtleties involved in the management of stress fractures, the primary treatment is modified activity. During the phase of modified activity, a number of important issues are attended to including modification of risk factors, maintenance of muscular strength and fitness, pain management, investigation of bone health, and prescription of orthotic devices. We divide the care of stress fractures into two phases: phase 1 is the early treatment using modified activity, and phase II is the period from the reintroduction of physical activity to full return to sport.

**Phase 1**

**Pain management.**

Pain is seldom severe but can be a problem even with normal walking. Mild analgesics or NSAIDs can be used as well as physical therapy modalities (e.g., ice, interferential electrical stimulation). In some cases where activities of daily living are painful, it may be necessary for the patient with a stress fracture to be nonweightbearing or partial weightbearing on crutches for a period of up to 7–10 d. In the majority of cases, this is not necessary and merely avoidance of the aggravating activity will be sufficient.

**Bracing.**

The use of a pneumatic brace (Air-Stirrup Leg Brace) has been described (29,68,70). All these studies have shown a markedly reduced return to activity time compared with average times in two of three studies (29,70) and compared with a “traditional treatment” group in the third (68). In this latter study, the brace group returned to full, unrestricted activity in an average of 21 d compared with 77 d in the traditional group. Once a stress fracture is clinically healed, the athlete is advised to use the brace during practice and competition.

The brace is thought to unload the tibia by compressing the lower leg, redistributing the forces and decreasing the amount of tibial bowing (70). Swenson and colleagues (68) propose that the pneumatic leg brace shifts a portion of the weightbearing load from the tibia to the soft tissue, resulting in less impact loading with walking, hopping, and running. They believe that the stabilization of the stress fracture contributes to earlier pain-free walking and an earlier completion of a functional progression program.

On the basis of this last study, patients with tibial stress fractures may well benefit from being placed in a long (40 cm) pneumatic leg brace (Aircast) at the time of diagnosis. It is important to remember that these studies have not shown accelerated healing of the stress fractures, only accelerated resumption of activity. Further studies need to be done in this area.

**Electrical stimulation.**

Various methods of electrical stimulation have all been shown to have a positive effect on healing of nonunion of traumatic fractures. These include pulsed electromagnetic fields (4–8,25,52,66,68), direct electric current (13,17,30,54), and capacitively coupled electric field (12,14–17,65). There have been no studies of the efficacy of this treatment on nonunion of stress fractures and only one nonblinded, uncontrolled study of its effect on time to return to sport in stress fractures in athletes.

Benazzo et al. (10) reported the results of a study on the treatment of stress fractures in athletes by capacitive coupling, a bone-healing stimulation method promoting bone formation by application of alternating current in the form of a sinusoidal wave. Twenty-two of 25 stress fractures were healed and two more showed improvement. The majority of these fractures were stress fractures of the navicular and 5th metatarsal, which are prone to delayed or nonunion. Further studies are required to determine the efficacy of this treatment in the management of tibial stress fractures.
**Muscular strength and endurance.**

Skeletal muscle has an important function in providing shock absorption to reduce the magnitude of the load delivered to the axial skeleton. In endurance sports, it is possible that even low levels of muscular fatigue can affect the total impact load to bone, particularly in the lower extremity. In the clinical setting, decrements in muscular strength and endurance may be undetectable whether testing manually or using a machine such as an isokinetic dynamometer. Muscular strength as measured by the torque generated by a single contraction against resistance is a function of stored ATP and PCr as well as neural factors. A more important measure is the fatigability of the muscle, which is a function of additional factors including substrate supply and utilization.

Because muscular strength and endurance are so important and yet subtle abnormalities are difficult to detect clinically, all athletes with stress fractures of the lower extremity should receive a specific program of muscular strengthening exercises in muscle groups surrounding the joints above and below the fracture line. Muscle-strengthening programs are usually prescribed for a period of 6 wk and begin immediately after diagnosis of the stress fracture.

**Maintaining fitness.**

Maintenance of fitness during periods of forced inactivity due to injury is a major concern to coaches and athletes. Inactivity has marked effects on the cardiovascular system as well as the metabolic and morphological characteristics of skeletal muscle. Reduction in various parameters of fitness have been reported after relatively brief periods of inactivity. Decrement in maximal stroke volume, cardiac output, and maximal oxygen uptake of approximately 25% have been reported after 20 d of bedrest (64). Other studies have shown a decline of 14–16% in maximal oxygen uptake with cessation of training for 6 wk (23, 55).

The effect of rest on performance varies from one athlete to another and depends on the particular sport. It is important that the athlete with a stress fracture be able to maintain strength and cardiovascular fitness while during phase 1. It should be emphasized to the athlete that during phase 1 the rehabilitation program is not designed to maintain or improve the patient’s fitness but rather to allow the damaged bone time to heal and gradually develop or regain full strength. Fitness should be maintained in ways that avoid loading the bone.

Nonloading activities that maintain fitness are those that use as many large muscle groups as possible without loading the bone. The recruitment of many large muscles results in high oxygen uptake and in substituting a nonloading activity for the athlete’s sport, the goal is to place an equal or greater demand on the cardiopulmonary system to supply large quantities of oxygen to the working muscles. The most common methods of maintaining fitness are cycling, swimming, water running, rowing, and StairMaster. For muscular strength, upper and lower body weight programs can usually be prescribed without risk. These workouts should as much as possible mimic the athlete’s normal training program in both duration and intensity.

Alternate activities have been shown to maintain $O_{2\text{max}}$ and muscular strength, but specific metabolic and neuromuscular adaptations that affect skill are not easily duplicated. For this reason, isolated skill related activities are resumed as early as possible in phase 1. It is possible in most cases for the athlete to maintain specific sports skills. In ball sports, these can involve activities either seated or standing still. This active rest approach also greatly assists the athlete psychologically.

**Modification of risk factors.**
As with any overuse injury, it is not sufficient to merely treat the stress fracture itself. Stress fractures represent the result of subtle, incremental overload. Subtle adjustments to the modifiable factors that contribute to the total load are an essential component of the management of an athlete with a stress fracture. A thorough history identifies the factors that have contributed to the injury and those that can be modified to reduce the risk of injury recurring. The fact that stress fractures have a high rate of recurrence is an indication that this part of the management program is often neglected.

The most common precipitating factors are probably training errors. Therefore, it is important to identify these and to discuss them with the athlete and his or her coach where appropriate. Training errors include sudden or rapid increases in training volume or intensity, at least at a rate greater than the time required for adequate adaptation of bone. Coaches need to be reminded that training regimens for athletes need to be individualized. What may be appropriate for most members of a team may be excessive for some.

Another important contributing factor may be inadequate equipment, especially running shoes. These shoes may be inappropriate for the particular foot type of the athlete may have general inadequate support or may be worn out. Shoes should be replaced approximately every 500 km. It is more important to replace shoes frequently than to buy the most expensive pair available.

Intrinsic biomechanical abnormalities are also thought to be a contributing factor to the development of overuse injuries in general and stress fractures in particular. Varus alignment, excessively supinated or excessively pronated feet may contribute to the development of stress fractures. Excessively supinated feet (pes cavus) generally give limited shock absorption and require footwear that compensates for this. Excessively pronated feet increase the degree of tibial torsion during gait and require appropriate footwear or custom made foot orthoses to control the excessive degree of pronation.

The management of the amenorrheic female athlete with a stress fracture is controversial. We would suggest treating each case individually. It may be possible to persuade the athlete to reduce the amount and intensity of her activity and/or increase her body fat, both of which may allow her menses to resume their normal pattern. If the athlete is unwilling or unable to follow that course, the possibility of hormonal supplementation should be discussed. The hormones are usually taken in the form of one of the low-dose oral contraceptive pills. However, traditionally there is considerable resistance by serious athletes to taking the OC pill on the grounds of possible weight gain. The role of bone density measurement in these patients is still unclear. Bone density measurement compares the patient’s bone density to the “average,” but it is known that bone density is increased in those involved in weight bearing exercise. We find bone density measurement useful in this group both to provide a baseline measurement before treatment and as an additional factor (if reduced) in convincing the athlete to commence treatment.

If after assessment of the athlete’s dietary intake there is evidence of inadequate overall caloric or calcium intake, dietary advice should be given by the clinician or the athlete referred to a dietitian. Athletes with stress fractures should consume 1500 mg of calcium and 400–800 IU of vitamin D per day.

It is important that by the time the athlete resumes training that these risk factors are corrected.

Phase 2
When normal, day-to-day ambulation is pain free, then resumption of the impact loading activities begins. The rate of resumption of activity should be modified according to symptoms and physical findings. For lower limb stress fractures where running is the aggravating activity, we recommend a program that involves initial brisk walking increased by 5–10 min per day up to a length of 45 min. Resumption of activity should not be accompanied by pain, but it is not uncommon to have some discomfort at the site of the stress fracture. If bony pain occurs, then activity should be ceased for 1–2 d. If pain free with normal ambulation, the activity is resumed at the volume and pace below the level at which the pain occurred. The patient should be clinically reassessed at biweekly intervals to assess the progress of the training program and any symptoms related to the stress fracture.

Once 45 min of continuous brisk walking is achieved without pain, slow jogging can begin for a period of 5 min within the 45-min walk. Assuming that this increase in activity does not reproduce the patient’s symptoms, then the amount of jogging can be increased by 5 min per session on a daily or every other day basis to a total of 45 min at slow jogging pace. This period of time is necessary to load the bone slowly and to be sure that adequate healing has occurred. Once the 45-min goal is achieved, pace can be increased, initially half pace then gradually increasing to full-pace striding. Once full sprinting is achieved pain free, functional activities such as hopping, skipping, jumping, twisting, and turning can be introduced gradually. It is important that this process is a graduated one, and it is important to err on the side of caution rather than try to return too quickly.

A typical program for an uncomplicated lower limb stress fracture resuming activity after a period of initial rest and activities of daily living is shown below (Fig. 7).
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<tbody>
<tr>
<td>Week 1</td>
<td>Walk 5</td>
<td>Walk 10</td>
<td>Walk 15</td>
<td>Walk 20</td>
<td>Walk 25</td>
<td>Walk 30</td>
<td>Walk 35</td>
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<tr>
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<td>Walk 20</td>
<td>Jog 10</td>
<td>Walk 15</td>
<td>Jog 20</td>
<td>Walk 10</td>
<td>Walk 5</td>
<td>Jog 45</td>
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<td>Walk 15</td>
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<tr>
<td>Week 3</td>
<td>Jog 40</td>
<td>Jog 35</td>
<td>Jog 30</td>
<td>Jog 25</td>
<td>Jog 40</td>
<td>Jog 35</td>
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<tr>
<td></td>
<td>Stride 5</td>
<td>Stride 10</td>
<td>Stride 15</td>
<td>Stride 20</td>
<td>Sprint 5</td>
<td>Sprint 10</td>
<td>Sprint 15</td>
</tr>
<tr>
<td>Week 4</td>
<td>Add functional activities</td>
<td>Gradually increase all week</td>
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<tr>
<td>Week 5</td>
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<td>RESUME FULL TRAINING</td>
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</tbody>
</table>

Figure 7 Activity program following uncomplicated lower limb stress fracture following period of rest and ADL.

This pattern of reintroduction of activity can be followed for other sports. For example, with aerobics classes, reintroduction of aerobic floor exercises should begin at 2 min per session with the remaining 18 min of “cardio” spent on the exercise bike. This ratio is gradually increased until the patient is back to full-time floor exercise.
It is not infrequent for the patient to experience pain at some point during the reintroduction of activity. This by no means is an indication of a return of the stress fracture. In each instance, the activity should be discontinued, followed by several days of modified rest, and then training should resume at a level lower than at which the pain occurred. If the clinician places the patient on an accelerated program for the reintroduction of activity, monitoring periods should be adjusted accordingly, and in some cases should be weekly. Progress should be monitored clinically by the presence or absence of symptoms and local signs. It is not necessary to monitor progress by radiography, scintigraphy, CT, or MRI since radiological healing often lags behind clinical healing. When training resumes, it is important to allow adequate recovery time after hard sessions or hard weeks of training. This can be accommodated by developing micro- and macro-cycles. Alternating hard and easy training sessions is a microcycle adjustment, but graduating the volume of work or alternating harder and easier sessions can also be done weekly or monthly. In view of the history of stress fracture, it is advisable that some form of cross training, e.g., swimming and cycling for a runner, be introduced to reduce the stress on the previously injured area and reduce the likelihood of a recurrence.

LONGITUDINAL STRESS FRACTURE

An unusual stress fracture of the tibia has been reported. Clayer et al. (21) presented two cases that ran longitudinally in the distal one third of the tibia. One was in a 24-yr-old man who developed pain while playing golf, and the second was in a 55-yr-old woman who developed pain while performing home duties. In both cases, plain radiographs were normal, but isotope bone scan showed increased uptake in the lower tibia. CT scan demonstrated a longitudinal fracture with callus formation. Both cases had clinical healing after restriction of activities. Previous reports of this fracture (1,35,46,50) were all in older patients (45–61 yr). Subsequently, this type of fracture has been reported by Krauss and Van Meter (42), Keating et al. (40), Jeske et al. (38), Umans and Kaye (69), and Feydy et al. (31).

Umans and Kaye (69) in their report of six cases describe the MRI appearances of this fracture. In each case MR imaging demonstrated linear marrow signal abnormalities orientated along the long axis of the tibial shaft. Endosteal and periosteal callus was identified on axial images. In all cases, MR imaging clearly demonstrated a fracture line extending through one cortex with abnormal signal in both the marrow cavity as well as adjacent soft tissues indicating edema.

Feydy et al. (31) compared the performance of CT and MRI in the diagnosis of longitudinal stress fractures of the tibia in 15 patients. The CT and MRI techniques allowed the detection of the fracture line in 82% and 73% of cases, respectively. The MRI technique, however, had a markedly higher sensitivity than CT in the detection of bone marrow edema (73% vs 18%) and soft tissue lesions (87% vs 9%).

ANTERIOR CORTEX STRESS FRACTURE

Stress fractures of the anterior cortex of the mid shaft of the tibia need to be considered separately as they are prone to delayed union, nonunion, and complete fracture. These fractures were first described by Burrows in 1956 (18) in ballet dancers.

The patient presents with diffuse dull pain aggravated by physical activity. The bone is tender to palpation at the site of the fracture, and periosteal thickening as evidenced by a palpable lump may be present if the symptoms have been present for some months.
In the acute stress fracture phase, plain radiographs are often normal although eventually periosteal thickening and callus will be seen in most cases. Isotope bone scan (Fig. 8) shows a discrete focal area of increased activity in the anterior cortex.

![Isotope bone scan appearance of stress fracture of the anterior cortex of the tibia.](image)

Figure 8 Isotope bone scan appearance of stress fracture of the anterior cortex of the tibia.

These stress fractures almost inevitably progress to nonunion and usually do not present to the practitioner until this stage. The radiographic appearance at this stage shows a defect in the anterior cortex which is termed “the dreaded black line” (Fig. 9). This appearance is due to bony resorption and is indicative of nonunion. The isotope bone scan at this stage will often fail to show any increase in uptake. At this stage, the patient will frequently have only minimal symptoms and be may be fully participating in sport.
Biopsies have demonstrated the presence of dense cortical bone and empty lacunae lacking osteophytes with sparse granulation tissue at the site of the nonunion (18,33,67). Some authors have described the histologic appearance as typical of a pseudoarthrosis (53,59). The mid-anterior cortex of the tibia is thought to be vulnerable to nonunion for two reasons: the area has a relatively poor blood supply and is also an area under tension due to the morphologic bowing of the tibia. Excessive anterior tibial bowing is often noted in association with this fracture.

Anecdotal reports from the literature indicate that only a relatively small proportion of these fractures will heal clinically and radiographically with conservative management consisting of an extended period of cast immobilization. Other forms of treatment advocated by various authors include pulsed electromagnetic stimulation, surgical excision and bone grafting (37,42) and transverse drilling at the fracture site (53). Chang and Harris (20) described five cases treated with intramedullary tibial nailing. They had two excellent results and three good results.

Pulsed electromagnetic fields (4–8,25,52,58,66), direct electric current (13,17,30,54), and capacitively coupled electric field (13–17,65) have all been shown to have a positive effect on healing of nonunion of traumatic fractures. No proper study has been performed to evaluate the efficacy of any of these treatments in the management of nonunion of stress fractures; however, it is reasonable to assume that they may be of some benefit.
Our recommended management of both the acute stress fracture and the established nonunion as denoted by the presence of a “dreaded black line” on plain radiograph is avoidance of the aggravating activity, the use of a long pneumatic leg brace (Aircast) and electrical stimulation for 10 h a day. Monitoring of fracture healing should be both clinical and radiographic. It is advised that athletes should not return to activity until there is evidence of cortical bridging on radiography. If after 4–6 months there is no evidence of healing both clinically and radiologically, drilling at the site of the fracture, insertion of an intramedullary rod, or bone grafting should be performed.

Recently, we have treated five patients with this condition surgically by “scalloping out” the area of bony cortex involving the fracture and inserting shavings from neighboring bone. These patients have all done well and returned to full activity an average of 2 months after surgery.

OTHER BONY PATHOLOGIES
Bony pathologies that can mimic stress fracture include tumor and infection. Osteoid osteoma is commonly mistaken for a stress fracture as it presents with pain and a discrete focal area of increased uptake on isotope bone scan. Two distinguishing features of osteoid osteoma are the presence of night pain and the relief of pain with the use of aspirin.

REFERENCES


## Exercise Program

### Week 1
- **Day 1**: Walk 5
- **Day 2**: Walk 10
- **Day 3**: Walk 15
- **Day 4**: Walk 20
- **Day 5**: Walk 25
- **Day 6**: Walk 30
- **Day 7**: Walk 35

### Week 2
- **Day 1**: Walk 20
- **Day 2**: Jog 10
- **Day 3**: Walk 15
- **Day 4**: Jog 15
- **Day 5**: Walk 10
- **Day 6**: Jog 5
- **Day 7**: Jog 15

### Week 3
- **Day 1**: Jog 30
- **Day 2**: Jog 25
- **Day 3**: Jog 20
- **Day 4**: Jog 15
- **Day 5**: Jog 10
- **Day 6**: Jog 5
- **Day 7**: Jog 5

### Week 4
- **Day 1**: Add functional exercises
- **Day 2**: Gradually increase weekly activities

### Week 5
- **Day 1**: Resume full training

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**Figure 7**

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