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Imaging of Stress Fractures in Runners

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Running is an extremely popular form of exercise. The emphasis today on the importance of exercise and weight loss and the convenience and low cost of running as a form of exercise have undoubtedly led to this popularity. Running-related injuries are common, however, and the current focus on the importance of health, diet, and fitness as well as competitive athletics has resulted in many individuals undertaking new or increasing levels of physical activity. This results in increasing levels of stress on the musculoskeletal system. Stress fractures in runners are a common problem, but the diagnosis and treatment is often challenging. Health care providers caring for recreational and professional athletes must be knowledgeable of the signs and symptoms of these injuries and maintain a high suspicion when seeing active patients seeking care for lower extremity and axial skeletal pain, because the signs and symptoms are often vague and overlap with other diagnoses.

PATHOPHYSIOLOGY

There is a spectrum of osseous stress injuries that occurs, beginning with stress reaction or stress response and eventually leading to stress fracture. The pathophysiology of stress reaction and stress fractures is related to the bone response to the repetitive stresses at the cellular level. With excess stresses, the osteoclasts replace the circumferential lamellar bone with dense osteonal bone. This is accompanied by the development of edema and hyperemia, which is the stress reaction or stress response that can be demonstrated by MRI. The relative muscle groups, which are also experiencing the repetitive stresses, respond with hypertrophy and strengthening more rapidly than bone, and this force is transmitted to the periosteum at the muscle attachments, resulting in periostitis. Stress fractures are microfractures of bone that result from repetitive physical loading of the involved bone, which can lead to complete fractures if the excessive stress on the bone continues [1,2].

Stress fractures fall into two general categories: fatigue stress fractures and insufficiency fractures. Fatigue stress fractures result from the exposure of

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normal bone to excessive repetitive stress. Fatigue stress fractures tend to be seen in a young, active, healthy population such as recreational and professional athletes and members of the military. Insufficiency fractures tend to occur in bones that are predisposed to fracture based upon osteopenia and osteoporosis, and these conditions are more commonly seen in the elderly population or in patients who have secondary causes of demineralization [3].

Most stress fractures occur 4 to 5 weeks after the onset of a new exercise. Muscles normally provide biomechanical dissipation of stress from the bones, but fatigued muscle may decrease this protective contribution, and this can result in the transmission of increased stress to the bones [4]. The incidence of stress fractures increase with advancing age [5]. The location of stress fractures in runners tends to also vary with age, with femoral and tarsal stress fractures occurring in older patients, and fibular and tibial stress fractures occurring in the younger athlete [6].

Runners are particularly at risk because of the multitude of factors that can result in the increased or altered stressors to the skeletal system. Stress fractures occur in 13% to 37% of runners [7]. There is a decreasing incidence of these fractures in the tibia (33%), navicular (20%), metatarsals (20%), femur (11%), fibula (7%), and pelvis (7%); in 75%, the medial tibial crest is involved [8]. Factors found to be associated with stress fractures include training errors, distance, age, running surfaces, shoes, diet factors such as malnutrition and anorexia nervosa, smoking, alcohol use, a history of overuse injuries, and hormonal alterations such as amenorrhea, inhaled corticosteroids, and hypothalamic dysfunction [7–11]. Certain biomechanical factors have been found to be associated with patients experiencing multiple stress fractures. These include a high longitudinal arch of the foot, leg-length inequality, and excessive forefoot varus. Females who have menstrual irregularities seem to have an increased risk of recurrent stress fractures. Runners who have high weekly training mileage have also been found to have an increased risk of recurrent stress fractures of the lower extremities [12].

BIOMECHANICS OF RUNNING

A discussion of running-related injuries necessitates a brief summary of the biomechanics of running. During running, each foot strikes the ground 50 to 70 times per minute for each foot. The force produced is two to four times the runner's body weight. This force is distributed through the runner's footwear, and transmitted upwards through the lower extremities and into the pelvis, sacrum, and spine, exposing these structures to increased axial stresses. There are two main phases of running: the support and airborne phases. The support phase consists of the heel strike, midstance, and toe-off. The airborne phase consists of the follow-through, forward swing, and descent. There are complex motions of the subtalar joint and other joints of the lower extremity during these phases. At heel strike, there is dorsiflexion and supination of the foot, and slight external rotation of the tibia. Following heel strike, the foot pronates during approximately 60% of the midstance phase, and there is internal rotation of the tibia on the talus [13]. The excessive stresses of each of these complex but normal biomechanical phases of the weight-bearing phase of running may be magnified by altered biomechanics such as excessive pronation or supination of the foot, pes planus and pes cavus deformities, genu alignment deformities, leg-length discrepancies, and scoliosis [13].

DIAGNOSIS

Patients who have osseous stress injuries most commonly present with insidious onset of activity-related local pain with weight bearing. If the athlete continues to exercise, the pain may become more severe or occur at an earlier stage of exercise [14]. Typically, the pain resolves when the patient is non-weight bearing [8]. Occasionally, the patient may present with additional findings of redness, swelling, and obvious periosteal reaction at the site of stress fracture. In most cases, the diagnosis of a stress fracture is a clinical one. Occasionally, however, the diagnosis may not be as straightforward, and imaging may be indicated to differentiate among other significant etiologies.

IMAGING

MRI of joints in sports medicine requires consideration of multiple technical factors. A dedicated extremity coil appropriate for the particular joint is desired. The type of abnormality clinically suspected, the magnet field strength, the desired anatomic coverage, and the presence of postsurgical change or indwelling hardware are important considerations. In the majority of cases of stress response as well as stress fracture, there is no abnormality on plain film radiographs [14]. Occasionally subtle periosteal reaction may be seen, but often there is no detectable cortical fracture line. Therefore, a heightened awareness of the signs, symptoms, and presentations of stress fractures must be maintained in order to avoid significant delays in diagnosis that can significantly alter the recovery time and prognosis of the injury. Normal plain films cannot exclude a stress reaction or stress fracture.

Bone scintigraphy is a highly sensitive imaging modality, but lacks specificity in small joints such as the ankle and foot. A triple-phase bone scan is typically performed, consisting of an immediate postinjection blood flow phase, a blood pool phase, and delayed 3 to 6 hour imaging. Activity is demonstrated in areas of new bone formation at sites of healing stress fractures where there is osteoblastic activity occurring. Stress fractures may be asymptomatic and found incidentally on bone scintigraphy or plain films [15].

CT is less commonly used for stress fracture imaging, but has been described as useful in the diagnosis of the uncommon longitudinal stress fractures of the tibia [16].

MRI has proven to be extremely useful in the diagnosis of stress reaction and stress fracture, and has a high degree of sensitivity and a higher degree of specificity relative to bone scintigraphy in terms of the site of injury [7,8,14,16–20]. MRI typically shows periosteal edema and bone marrow edema without a visible fracture line in cases of stress reaction without fracture. There may be a variable degree of surrounding soft-tissue edema. Enhancement of the marrow and surrounding soft tissues may be seen after contrast administration, mimicking other disease such as infection or tumor. Similar findings with the additional finding of a low signal cortical fracture line are seen with stress fractures [14].

A discussion of the various locations where stress-related injuries tend to occur follows, in a distal to proximal order (Table 1).

GREAT TOE AND SESAMOIDS

Stress fractures of the great toe and sesamoids are seen less frequently than other sites of stress-related injury, but when they do occur the diagnosis may be more difficult, resulting in a delay in diagnosis if this injury is not considered [8]. Stress fractures of the great toe have been reported in runners, soccer players, and volleyball players. Athletes who have pain in the first metatarsophalangeal joint and who are exposed to excessive running, jumping, and repeated forced dorsiflexion of the first metatarsophalangeal seem to be predisposed to this injury [21]. As with stress-related injury in other locations, the symptoms typically occur during training without a history of trauma. Approximately 1% of all running injuries involve the sesamoids; 40% of these are stress fractures and 30% are sesamoiditis [22]. Sesamoiditis/osteochondritis, avascular necrosis, stress response of the synchondrosis of partite sesamoid bones, traumatic fractures, osteomyelitis, and bursitis between the tibial sesamoid and the tendon of the flexor hallucis brevis may all occur in this location. One or both sesamoid bones may be involved.

Plain films are commonly normal. Nuclear scintigraphy may show focal increase radiotracer activity over one or both sesamoid regions. MRI of sesamoid stress response and stress fractures most commonly shows low T1 signal intensity and increased signal intensity on T2 and short-tau inversion-recovery (STIR) sequences (Fig. 1A, B).

MRI signal alterations of stress response of sesamoids and sesamoiditis overlap. Increased STIR signal intensity and low T1 signal have been described with sesamoid stress response, as opposed to increased STIR signal intensity and normal T1 signal, which favor sesamoiditis. Sesamoiditis also more commonly involves both sesamoid bones, and may be associated with bursitis, tendinosis, and tenosynovitis [23,24].

Table 1
Most common sites of stress injuries

Location	Incidence
Tibia	33%
Navicular	20%
Metatarsals	20%
Femur	11%
Fibula	7%
Pelvis	7%

From Csizy M, Babst R, Fridrich KS. ''Bone tumor'' diagnostic error in stress fracture of the medial tibial plateau. Unfallchirurg 2000;103(11):993–5 [in German].

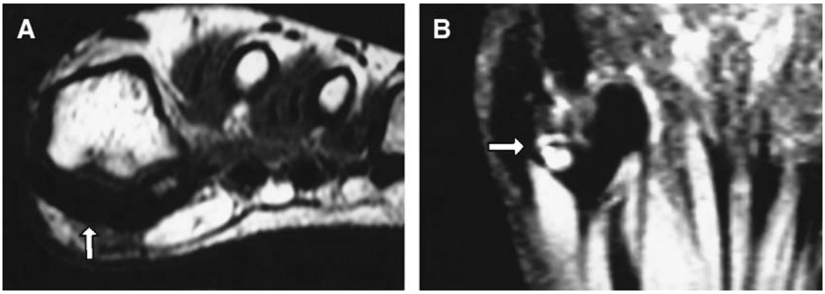

Fig. 1. (*A*) Axial T1 SE. Medial sesamoid stress fracture. Seventeen-year-old runner with replacement of fat marrow signal by edema (*arrow*) related to the stress fracture. (*B*) Coronal T2 FSE fat-suppressed (FS), same patient. Medial sesamoid stress fracture. Transverse low signal line consistent with fracture plane (*arrow*).

Treatment typically involves avoidance of physical activity and attention to predisposing extrinsic factors such as footwear [25,26]. Hulkko and Orava [27] reported 15 cases of stress fractures of the hallucal sesamoids in athletes. The mean patient age was 22.3 years old. Nine patients were males and 6 were females. Eight fractures involved the medial sesamoid, six involved the lateral sesamoid, and in 1 patient both sesamoids were involved. Ten patients were treated conservatively. Five patients required surgical excision of the fragmented involved sesamoid and gradually returned to training 6 to 8 weeks after surgery. Pathology confirmed fibrotic nonunion of the stress fractures [27].

METATARSAL BONES

Metatarsal stress fractures are a common overuse injury in runners [28,29]. Along with the tibia, the metatarsals are among the most common stress fractures seen in runners [28].

It is thought that the plantar flexion musculature of the toes help to dissipate stress on the metatarsals. It has been demonstrated that dorsal strains are significantly reduced by simulated contraction of the plantar flexion musculature. It is therefore possible that fatigue of these muscles during strenuous or prolonged running may result in decreased dissipation of forces by the musculature and increased exposure of the stress to the metatarsals [29,30].

A metatarsal biomechanical model has been proposed as a link between the increased incidence of second and third metatarsal stress fracture, and the relative bending strain forces and shear forces as measured beneath these lesser metatarsal heads during distance running. The bending strain in the second metatarsal has been reported as 6.9 times greater than the bending strain in the adjacent first metatarsal bone. Shear forces are also reported as greatest in the second metatarsal in comparison with other metatarsal bones. Axial forces are greatest in the first metatarsal [31]. The second through fourth metatarsals have been reported as the weakest metatarsals in terms of their cross-sectional geometric properties; however, the second and third metatarsals experience relative increased stress during walking and running [32]. The relative lengths of the first and second metatarsal do not seem to have an increased incidence of associated stress fracture risk to the second metatarsal [33].

MRI is useful for imaging stress injuries of the metatarsals. Plain films of metatarsal stress injuries are often negative. Nuclear scintigraphy often is less specific as to the exact location of injury in the small bones of the foot. MRI of stress response typically shows intramedullary low T1 signal and corresponding increased T2, fat-saturated, or STIR signal intensity, and may show enhancement of the corresponding marrow as well as surrounding soft tissues after contrast administration. It is critical to correlate these MRI findings with the clinical presentation because neoplasm and infection may show similar findings (Fig. 2).

An actual stress fracture will show the above findings associated with stress response, with the additional finding of a low T1, low T2 signal intensity line extending to the cortex representing the fracture plane (Fig. 3) [24,34–36].

Fractures of the proximal fourth metatarsal bone are less common than distal fourth metatarsal fractures, and have a longer healing time. This is similar to proximal fifth metatarsal injuries and stress fractures. Patients may continue to be symptomatic even after 3 months of rest and immobilization. Ideal treatment appears to involve prolonged combination of non-weight–bearing casting followed by weight-bearing casting [37]. The fifth metatarsal stress fracture may occur in the metatarsal shaft in runners in contradistinction to the Jones fracture, which is a fracture through the base of the fifth metatarsal (Fig. 4).

Delayed union and nonunion may occur in a significant number of these injuries. Delayed unions of Jones fractures may occur in up to 67% of cases treated conservatively. Immediate intramedullary screw fixation of Jones fractures and proximal shaft fifth metatarsal fractures has been reported to have nearly 100% union rates, with an average time to union being approximately 6 to 8 weeks. Intramedullary fixation has been recommended as the treatment of choice for these fractures to achieve improved union rates [38,39]. More recently, however, it has been suggested that intramedullary screw fixation alone does not always adequately address the torsional stress created by the insertion of the peroneus brevus on the proximal fragment of the fifth metatarsal in fifth metatarsal fractures. It has been suggested that optimal internal fixation appears to require internal devices or fixation that also addresses the torsional stresses [40].

TARSAL BONES

Up to 20% of stress fractures in runners may occur in the tarsal bones [8]. Stress fracture of the tarsal bones are too often a diagnostic challenge, because many providers do not consider tarsal stress fractures in the assessment of foot and ankle pain. A high clinical suspicion of stress fractures is required for an accurate and timely diagnosis. The majority of tarsal bone stress fractures occur in the navicular (Fig. 5A, B) [28].

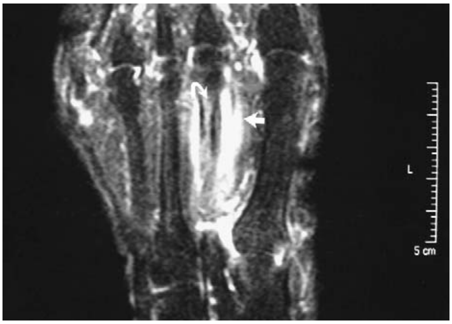

Fig. 2. Second metatarsal stress fracture. Fifty-one-year-old female with right foot pain for 2 weeks after recent increase in mileage using a treadmill. Coronal STIR image shows diffuse bone marrow edema (*curved arrow*), periosteal edema, and soft-tissue edema (*straight arrow*) involving and surrounding the second metatarsal shaft. No underlying fracture line is seen.

This diagnosis is becoming recognized with increasing frequency as physicians become more familiar with the condition. The running athlete who develops dorsal midfoot pain radiating to the medial arch should suggest the possibility of this injury. Recent studies have shown that track athletes accounted for 59% of all tarsal navicular stress fractures [28].

Rarely, stress fractures may occur in the cuboid bone. Diagnosis may again be delayed secondary to this diagnosis not being considered. It may mimic peroneal tendon pathology [41,42]. Stress fractures of the talus and calcaneus also occur in runners (Fig. 6) [43–47]. Plain film will most often be normal, and MRI is the imaging modality of choice for detection, localization, and

Fig. 3. Third metatarsal stress fracture. Sixty-year-old female runner with subacute onset of midfoot pain and tenderness. Coronal STIR image showing bone marrow edema (*curved arrow*) and a transverse stress fracture through the distal third metatarsal neck (*straight arrow*).

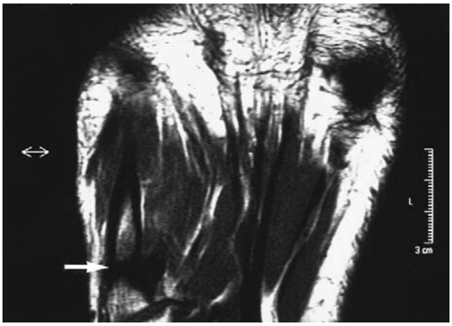

Fig. 4. Healing fifth metatarsal stress fracture. Seventeen-year-old male high school football player. Coronal T1 SE image shows transverse low signal intensity through the base of the fifth metatarsal (*straight arrow*).

characterization of tarsal bone stress fractures. MRI most often demonstrates marrow edema or a cortical fracture line [17].

Nondisplaced and noncomminuted tarsal bone fractures may be treated with conservative management with casting and non-weight bearing for 6 weeks. Displaced or comminuted fractures are indications for surgical intervention, which may include screw fixation or autologous bone grafting, depending on the nature and age of the fracture [17,48]. Evaluation of footwear is important to prevent recurrence.

TIBIA

The tibia is the most common site of stress-related injury in runners [6,8]. Leg pain is common in runners, and may be caused by a number of etiologies,

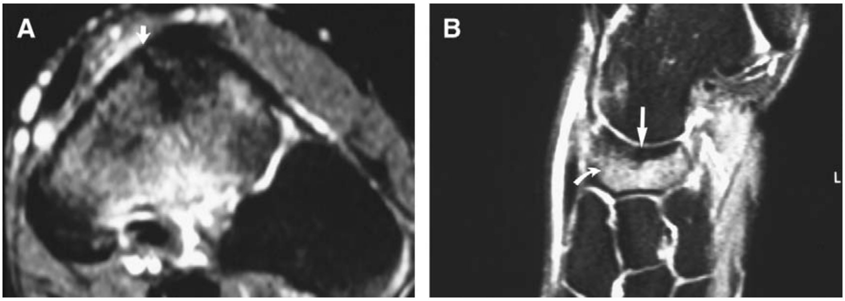

Fig. 5. Navicular stress fracture. (*A*) Twenty-seven-year-old female tennis pro with pain and tenderness along the medial aspect of the navicular. Axial T2 SE image shows increased signal intensity within the navicular consistent with bone marrow edema, with a low-signal vertical line interrupting the dorsal cortex, consistent with a stress fracture (*straight arrow*). (*B*) Same patient. Coronal oblique T2 SE image shows increased signal intensity within the navicular, consistent with bone marrow edema (*curved arrow*), with a low-signal vertical line interrupting the dorsal cortex consistent with a stress fracture (*straight arrow*).

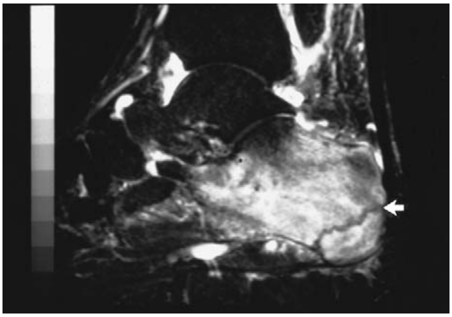

Fig. 6. Calcaneal stress fracture. Sagittal STIR image showing linear low signal fracture line (*arrow*) and extensive bone marrow edema in a long distance runner with heel pain and tenderness.

including: tibial periostitis (shin splints), stress reaction, stress fractures, muscle/tendon injuries, and compartment syndromes. Tibial stress reaction and stress fractures most commonly present with pain and tenderness along the medial shaft of the tibia, precipitated by exercise.

There is usually focal tenderness to palpation and percussion along the medial tibia. Tibial stress fractures can involve the diaphysis, metaphysis, and malleoli, and can be transverse, longitudinal, or spiral (Fig. 7) [16,49,50].

Stress fractures of the tibial diaphysis are common among runners. The proximal tibial metaphysis is a relatively unusual site of stress fracture, and can mimic internal derangement of the knee. It has been suggested from research on bone geometry that runners with significantly smaller tibial cross-sectional dimensions and area as determined by CT and dual energy x-ray absorptionmetry (DXA) are at greater risk for the development of tibial stress fractures [51].

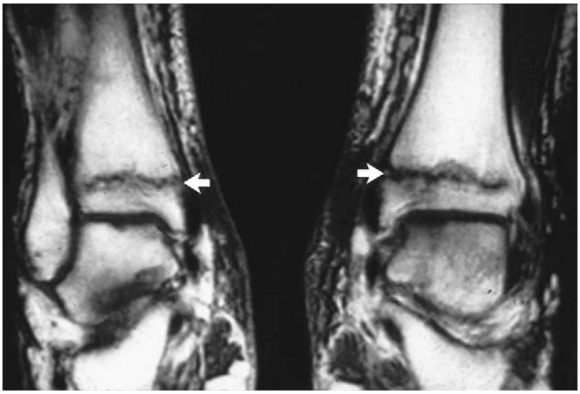

Fig. 7. Bilateral distal tibial metaphyseal stress fractures (*arrows*). 64-year-old female vacationing in Hawaii and hula dancing for 2 weeks developed bilateral ankle pain.

Diagnosis is commonly made clinically. An early radiographic sign of stress fracture termed the "gray cortex" has been described in initial conventional radiographs [52], but most plain films are normal in the setting of stress injuries [53]. Bone scintigraphy may show longitudinal uptake of radiotracer along the posteriomedial tibial diaphysis, at the attachment of the soleus in shin splints. Transverse tibial stress fractures of the diaphysis manifest as focal elliptical or fusiform cortically based radiotracer activity on the delayed bone scan imaging (Fig. 8) [54].

A recent study comparing MRI, CT, and bone scintigraphy described MRI as the single best technique to assess suspected tibial stress injuries [53]. The sensitivities of MRI, CT, and bone scintigraphy were 88%, 42%, and 74% respectively. The specificity, accuracy, and positive and negative predicted values were 100%, 90%, 100%, and 62% respectively for MRI and 100%, 52%, 100%, and 26% respectively for CT [53]. Using MRI, the transverse plane has been determined to be the best in the detection of tibial shaft stress injuries. Axial MR images may show endosteal marrow edema, subtle periosteal edema, and a thickened detached periosteum manifested as a thin line of signal void [53,55]. CT can show osteopenia in the tibial cortex, which is the earliest finding in cortical bone fatigue injury. CT may also show subperiosteal irregularity and cortical resorptive change [53].

Longitudinal stress fractures are an unusual but recognized injury in runners [16]. Longitudinal tibial stress fractures present as elongated, diffuse, increased radiotracer activity extending from the tibiotalar area proximally. This may be suggested on the soft-tissue blood pool phase of the triple-phase bone scan, but is best seen on the 3-hour delayed imaging [50]. Plain films are most often negative, and reports of negative bone scans in longitudinal tibial stress fractures

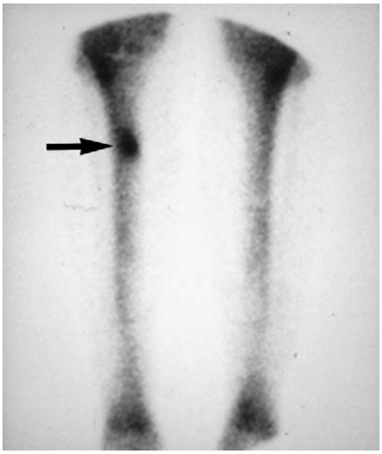

Fig. 8. Tibial stress fracture. Delayed nuclear scintigraphy shows focal fusiform uptake of radiotracer activity in the proximal tibial diaphysis consistent with a stress fracture (*arrow*).

have been noted [16]. MRI diagnosis of longitudinal fractures may be challenging in that findings may consist only of longitudinal, intramedullary, hyperintense signal intensity seen with STIR sequences. T1-weighted sequences may show corresponding less obvious decreased signal intensity. An actual fracture line may not be seen on MRI in longitudinal stress fractures of the tibia. In these cases, CT with thin section reformats may reveal an intracortical longitudinal fracture line, confirming the diagnosis [16].

Fredericson and colleagues [56] have proposed an MRI grading system as a method of describing a continuum of stress injuries of the tibia. Grade 1 injury consists of only periosteal edema on T2-weighted, fat-suppressed images without marrow or cortical signal abnormality. Grade 2 shows both periosteal edema and marrow edema on fat-suppressed, T2-weighted images, but no corresponding decreased signal on the T1-weighted images. Grade 3 injuries show moderate to severe edema of both the periosteum and of the marrow on both the fat-suppressed T2 and the T1-weighted sequences. Grade 4 injury shows grade 3 signal changes, with the addition of the actual cortical fracture line being visible. Fredericson and colleagues recommended MRI over bone scintigraphy as a more informative and accurate test to determine the extent of underlying bone injury, which allows better recommendations for clinical management without the exposure to ionizing radiation characterized by bone scintigraphy, along with significantly reduced imaging times [56]. MRI results must be correlated with the clinical setting, however, because signal changes suggestive of tibial stress reaction may be seen in asymptomatic long distance runners. Bergman and coworkers [57] followed 21 asymptomatic collegiate long distance runners, and reported that 67% were normal, but that the other 43% of asymptomatic long distance runners showed grade 1 to grade 3 signal changes. No asymptomatic subjects were found to have grade 4 injuries. All subjects remained asymptomatic for a 2-year follow-up time period [57]. This demonstrates the importance of correlating imaging findings with clinical findings before management decisions. Treatment consists of activity restriction and modification in milder cases and non-weight bearing or immobilization in more severe cases.

Tibial stress fractures in runners may occur less commonly in locations such as the medial tibial condyle and medial malleolus. These injuries are particularly difficult to diagnose clinically because they may mimic other regional injuries such as meniscal tears, ligamentous, or cartilaginous pathology [8,58]. Stress fractures may result in a large amount of bone marrow signal alteration that may be mistaken for malignant tumors, resulting in unnecessary biopsy [8]. Meniscal tears may be associated with adjacent bone marrow edema as a stress response to the meniscal tear, or may be an asymptomatic incidental finding in the setting of a symptomatic stress fracture of the proximal tibia. Patterns of signal alteration and clinical correlation are important discriminators of these injuries (Figs. 9, 10).

Medial malleolus stress fractures are rare. They most commonly present with subacute or chronic pain and tenderness over the medial malleolus, or

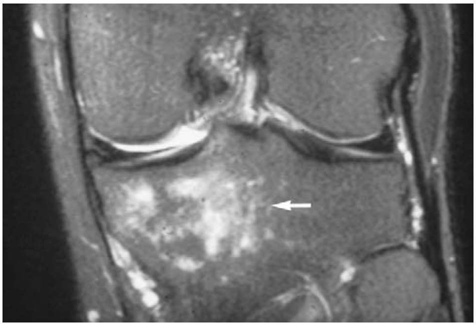

Fig. 9. Tibial metaphyseal stress response. Coronal T2 FSE FS image. Thirty-two-year-old male long distance runner with pain and tenderness just distal to the medial joint line. Medial proximal tibial metaphyseal bone marrow edema (*arrow*) without fracture line consistent with stress response.

medial ankle pain with a history of running. An ankle effusion may be present [59,60]. Plain films are most often normal. Bone scan normally shows uptake of radiotracer in the medial malleolus. [59–61]. CT may show the presence of subtle fissures at the junction of the medial malleolus and tibial plafond, and circumscribed lytic lesions have been reported with medial malleolus stress fractures [61]. These patients may be treated conservatively or operatively, depending on the severity of the injury and its radiographic appearance, or lack of response to conservative treatment [59,60,62]. It has been suggested that stress fractures in athletes desiring an early return to full activities that are visible by plain film should be treated by open reduction and internal fixation with cancellous screws. Patients who have bone scan or MRI evidence of medial malleolus stress fracture that are not evident on plain film may be treated conservatively with casting and immobilization [60].

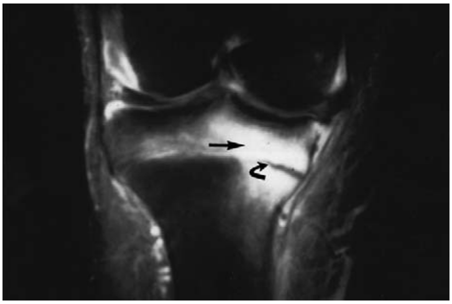

Fig. 10. Transverse tibial metaphyseal stress fracture. Coronal T1, contrast-enhanced FS. Long distance runner with pain and tenderness just distal to the medial joint line. Low signal intensity transverse fracture line is visible (*curved arrow*) with surrounding enhancing bone marrow edema (*straight arrow*).

A study measuring in vivo tibial strain rates found that strain rates were 48% to 285% higher during overground running in comparison with treadmill running [63]. The authors in the study suggest that treadmill runners are at a lower risk of developing tibial stress fracture, but less likely to achieve tibial bone strengthening than over-ground runners [63].

Stress fractures of the anterior tibial midshaft cortex are injuries that require particular attention, because they are prone to delayed healing and nonunion. Rest and external electric stimulation for 3 to 6 months have been suggested as initial management in these patients before surgical intervention. In one study, the average time to return to competitive activity was 12.5 months using this management [64]. Chronic, recurrent, or recalcitrant stress fractures of the tibia that do not heal with nonoperative therapy may benefit from intramedullary tibial nailing [65].

FIBULA

Stress fractures of the fibula may occur in runners, presenting as local pain and tenderness over the fibula. The incidence of stress fractures in the fibula in running has been quoted between 7% and 12%, and is most common in the distal fibula [6,8,66]. Proximal fibular stress fractures may also rarely occur, but are more common in jumpers. A high clinical suspicion is particularly important in making both of these diagnoses. Fractures may present as pain and tenderness over the lateral proximal fibula or as knee pain, requiring a high clinical awareness to make the correct diagnosis [67,68]. Imaging findings are similar to findings in the tibia.

PATELLA

Two types of patellar stress fractures occur: longitudinal and transverse [69]. It has also been suggested that in some cases a chronic symptomatic bipartite patella could represent a chronic patellar stress fracture [70]. An exceptionally rare case of a running related transverse patellar stress fracture in a 12-year-old misdiagnosed for 5 months as Sinding-Larsen-Johansson disease has been reported [71]. These cases illustrate the need to consider stress injuries, even when the patient's signs and symptoms are more typical for an alternative diagnosis. Considering this diagnosis early on may result in an early diagnosis, which may significantly alter the course of the injury and shorten the recovery time. Imaging findings of patellar stress injuries will typically parallel findings in other locations.

FEMUR

Stress fractures of the femur in runners may occur in the femoral neck, trochanteric and subtrochanteric region, and femoral shaft. These injuries are often not considered in the initial presentation, and a high index of suspicion must be maintained. Patients commonly present with hip, groin, gluteal, thigh, or knee pain, depending on the location of the injury [18,72,73].

In a study by Clement and colleagues [72], 71 patients who had 74 stress fractures of the femur were studied. Nearly 95% were runners. Forty-six percent had anterior thigh pain, 45% had hip pain, and 8% had groin pain. Pain could be reproduced in 70% of patients when they were asked to hop on the affected limb. Bone scans showed a distribution of stress fracture location as 53% in the femoral shaft, 20% in the lesser trochanter, 15% in the intertrochanteric region, 11% in the femoral neck, and 1% in the greater trochanter. Only 24% of the 46 plain films acquired were abnormal. The average time to diagnosis was 6.6 weeks. The average time to recovery was 10.4 weeks [72].

In general, stress fractures of the femoral neck may occur along the medial or lateral margin of the neck (Fig. 11A, B). Distraction or tension stress fractures tend to occur along the lateral femoral neck in older patients, whereas compression stress fractures occur along the medial femoral neck, and tend to occur in younger, active patients. Patients typically present with activity related pain, and pain is often reproduced with passive range of motion, particularly internal rotation [74]. Patients commonly present with hip, groin, gluteal, thigh, or knee pain [72,74]. A high clinical suspicion is required in athletes presenting with exertional pain in these areas and with hip pain in extreme ranges of motion. Stress fractures may progress to complete fractures, and complete fractures may displace, which significantly worsens the long-term outcome. The average delay in diagnosis in other series is reported up to 14 weeks, which can result in a nondisplaced fracture advancing to displacement. The displacement of femoral neck fractures is the main determinant of prognosis. Displaced fractures result in a 60% reduction in patient activity level in sports. There is an associated 30% risk of avascular necrosis of the femoral head [75].

Femoral neck stress fractures may be bilateral. Voss and coworkers [76] reported a case of bilateral stress fractures of the femoral neck in a 30-year-old amenorrheic patient who had low caloric intake. Stress fractures of the femoral neck in children who have open capital femoral epiphysis are very rare, but

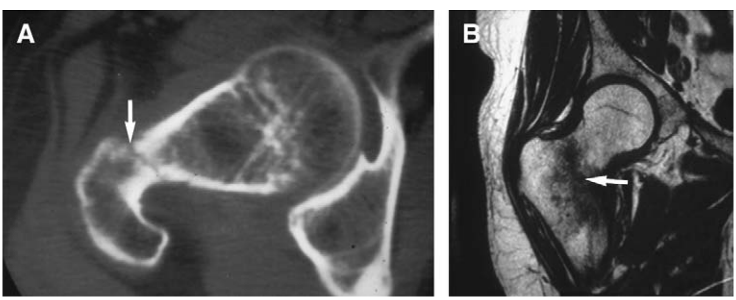

Fig. 11. 72-year-old physician with a femoral neck stress fracture who developed right hip pain rehabilitating on a treadmill following a myocardial infarction. (*A*) Axial CT. Nondisplaced fracture line is seen in the medial femoral neck (*arrow*). (*B*) Coronal T1-weighted SE. There is vertically oriented low T1 signal intensity in the medial femoral neck consistent with fracture plane (*arrow*).

have been reported. One reported case has been published of a 8-year-old child who had bilateral femoral neck fractures [19].

Diagnosis is most often made on the basis of clinical and radiographic information. Conventional radiographs are often normal, and MRI has proven valuable in the diagnosis of these injuries [77]. MRI of stress response typically shows intramedullary low T1 signal and corresponding increased T2, fat-saturated or STIR signal intensity, and may show enhancement of the corresponding marrow as well as surrounding soft tissues after contrast administration.

An actual stress fracture will show the above findings associated with stress response, with the additional finding of a low T1, low T2 signal intensity line extending through the cortex representing the fracture plane (Fig. 12A–C) [24,34–36].

Treatment of femoral stress fractures depends on the location, character, and extent of the stress fracture. Early stress reaction and nondisplaced compression-type stress fractures of the femoral neck may be treated conservatively with non-weight bearing and frequent radiographic follow-up. Surgical fixation is required for tension-type stress fractures, larger cortical defects, or displaced fractures [3].

Stress fractures of the femoral shaft most commonly occur in the proximal third of the femur. They may also occur in the mid and distal thirds. In these locations they may present with anterior thigh pain, vague thigh pain, and diffuse tenderness (Fig. 13).

Clinical and radiographic correlation cannot be overemphasized. In one reported case [18], a 42-year-old runner's anterior thigh pain was treated as a muscle strain. Symptoms persisted and the patient underwent an MRI of the knee, which revealed a mild degenerative meniscal tear that was then assumed to be a cause of femoral pain radiating to the knee. During positioning of the patient

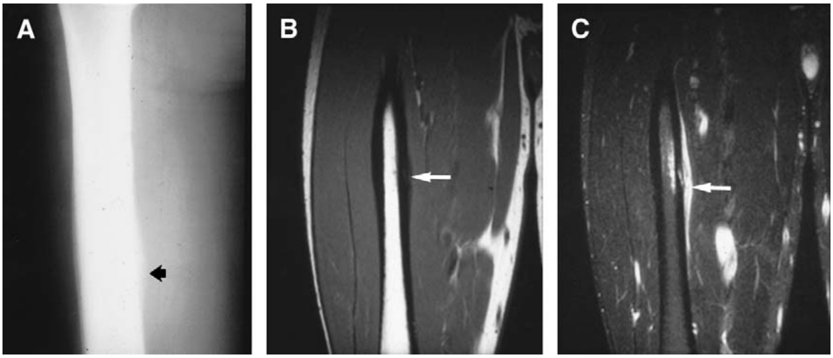

Fig. 12. 19-year-old male basketball player running sprints. (*A*) Conventional radiograph shows a healing stress fracture midfemur with nonaggressive periosteal reaction (*arrow*). (*B*) Coronal T1 SE. Healing stress fracture midfemur with nonaggressive periosteal reaction (*arrow*). (*C*) Coronal STIR. Healing stress fracture mid femur with nonaggressive periosteal reaction, and periosteal, endosteal, and soft-tissue edema (*arrow*).

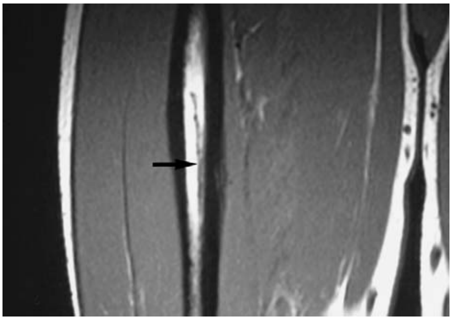

Fig. 13. Longitudinal femoral stress fracture. 19-year-old with thigh pain related to running. Coronal T1 SE image shows thin low signal intensity longitudinal line in the femoral diaphysis consistent with a longitudinal stress fracture (*arrow*).

in the operating room for arthroscopy, a complete fracture occurred through an undiagnosed supracondylar stress fracture, which was retrospectively manifested by intramedullary and periosteal edema on the prior MRI [18].

Conservative treatment is often successful in the treatment of these fractures. Often athletes can return to activity in 8 to 14 weeks [78].

PELVIS

Pelvic stress fractures are relatively uncommon, representing only 1% to 2% of all stress fractures [79,80]. Pelvic stress fractures in runners most often occur in the pubic rami. Pubic rami fractures are commonly near the symphysis pubis (Fig. 14).

Symptoms most commonly include groin, hip, buttock, or thigh pain [79–84]. These fractures most commonly occur in long distance female runners [81–85]. Severe groin pain may make running impossible. Standing on the leg of the affected side may elicit the pain or be impossible. Deep palpation

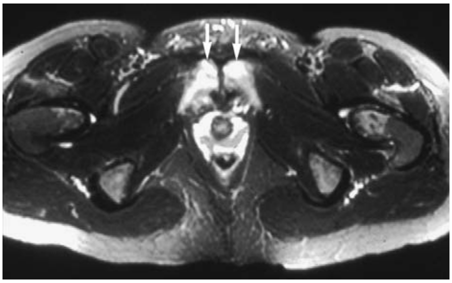

Fig. 14. Axial T2 FSE FS. Bilateral parasymphaseal stress fractures. 34- year-old female marathon runner who resumed training for a marathon postpartum. There is bilateral parasymphaseal bone marrow edema and small fracture lines were evident in the parasymphaseal regions consistent with stress fractures (*arrows*).

of the pubic rami may elicit extreme tenderness and help differentiate an overlying soft-tissue etiology such as muscle strain [84]. Pubic rami fractures are often nondisplaced and may be difficult to appreciate on plain film radiographs.

SACRUM

Sacral stress fractures may present as low back or buttock pain, mimicking disk disease, sciatica, or sacroiliac joint pathology. These fractures more commonly affect the female runner; there are reports of adolescent female runners who had low back pain subsequently being diagnosed with sacral stress fractures (Fig. 15) [86].

This emphasizes the need to consider stress injuries in the active pediatric patient population as well [87,88]. Imaging of sacral stress fractures may include nuclear scintigraphy, CT, and MRI. Bone scan classically shows uptake paralleling the sacroiliac joints. CT may show linear sclerosis with cortical interruption. MRI may show linear signal alteration paralleling the sacroiliac joints [89].

SPINE

Stress injuries of the spine in runners may occur in the vertebral bodies, pedicles, and in the lamina/pars interarticularis. Patients most commonly complain of low back pain (Fig. 16) [90].

MRI of stress response typically shows intramedullary low T1 signal and corresponding increased T2, fat-saturated or STIR signal intensity, and may show enhancement of the corresponding marrow as well as surrounding soft tissues after contrast administration. An actual stress fracture will show the above findings associated with stress response, with the additional finding of a low T1, low T2 signal intensity line extending to the cortex representing the fracture plane [24,34–36].

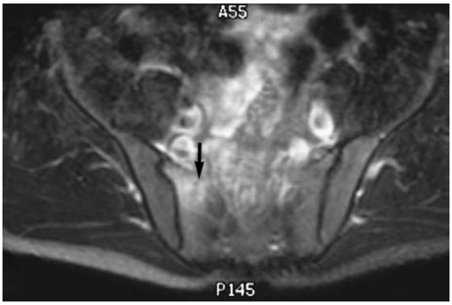

Fig. 15. Axial T2 FSE FS. Sacral stress fracture. 44-year-old radiologist and ultramarathon runner who developed low back and pelvic pain. There is increase signal intensity in the right side of the sacrum consistent with stress response. A subtle fracture line is evident (*arrow*).

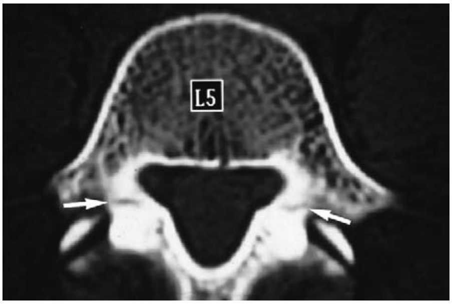

Fig. 16. Axial CT. Bilateral pedicle stress fractures. 14- year-old soccer player with pain that developed during running. Stress fractures of the pedicles (*arrows*) surrounded by transverse sclerosis on CT.

TREATMENT OF STRESS INJURIES

Successful treatment of stress injuries requires identification of the predisposing factor. A prolonged period of rest may result in resolution of pain, only for the symptoms to recur when the patient resumes running activities. A thorough review of training schedule, footwear, running surfaces, and other predisposing factors such as dietary and hormonal status should be performed. Most stress fractures can be managed with cessation of running and other lower extremity impact-type sports, with weight bearing only during normal daily activities. Cardiovascular fitness can be maintained with non-impact type sports such as cycling and swimming. Most stress fractures will heal in 6 to 8 weeks if compliance with protected weight bearing is followed [14].

SUMMARY

Stress fractures in runners are a common problem, but their diagnosis and treatment are often challenging. A high level of suspicion and awareness of these injuries should be maintained when caring for physically active patients, in order to avoid misdiagnoses or delays in diagnosis. MRI can be particularly helpful for the diagnosis and characterization of osseous stress injuries in the running athlete.

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