

[Primary Care]



Stress Fractures of the Foot and Ankle in Athletes

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Context: Stress fractures of the foot and ankle are a common problem encountered by athletes of all levels and ages. These injuries can be difficult to diagnose and may be initially evaluated by all levels of medical personnel. Clinical suspicion should be raised with certain history and physical examination findings.

Evidence Acquisition: Scientific and review articles were searched through PubMed (1930-2012) with search terms including *stress fractures* and 1 of the following: *foot ankle, medial malleolus, lateral malleolus, calcaneus, talus, metatarsal, cuboid, cuneiform, sesamoid, or athlete.*

Study Design: Clinical review.

Level of Evidence: Level 5.

Results: Stress fractures of the foot and ankle can be divided into low and high risk based upon their propensity to heal without complication. A wide variety of nonoperative strategies are employed based on the duration of symptoms, type of fracture, and patient factors, such as activity type, desire to return to sport, and compliance. Operative management has proven superior in several high-risk types of stress fractures. Evidence on pharmacotherapy and physiologic therapy such as bone stimulators is evolving.

Conclusion: A high index of suspicion for stress fractures is appropriate in many high-risk groups of athletes with lower extremity pain. Proper and timely work-up and treatment is successful in returning these athletes to sport in many cases. Low-risk stress fracture generally requires only activity modification while high-risk stress fracture necessitates more aggressive intervention. The specific treatment of these injuries varies with the location of the stress fracture and the goals of the patient.

Keywords: stress fracture; athlete; foot; ankle

INTRODUCTION, EPIDEMIOLOGY, AND BASIC SCIENCE

Stress fractures are relatively uncommon injuries, accounting for approximately 1% to 7% of all athletic injuries.^{12,35} The incidence of these injuries is rising due to earlier and longer participation in sports, the emergence of more extreme sporting activities, and the heightened awareness of the diagnosis.³⁵

In contrast to acute fractures, which typically occur with a single maximal load, stress fractures occur due to repetitive, submaximal loading of a bone, leading to microfractures that are unable to heal due to bone resorption and bone formation imbalances.¹² A bone responds to stress on a continuum from a stress reaction to a fracture.^{12,13} The initial stage of bone failure is generally called a stress reaction. This diagnosis is made in a symptomatic patient who has bone scan or magnetic resonance imaging (MRI) evidence of bone reactive changes without a

true fracture line.^{12,13} If the repetitive loading continues, the stress reaction can go on to a true stress fracture.^{12,13} This mechanism of injury explains the higher incidence of stress fractures among military recruits, runners, and those involved in jumping sports, though any activity with repetitive loading can lead to stress fractures.^{8,12,13,17,35} Most bones have reported cases of stress fractures, but the lower extremities have the highest prevalence.¹² In a study of 320 athletes, the tibia (49.1%), tarsals (25.3%), and metatarsals (8.8%) were the most frequently involved bones affected by a stress fracture.⁵⁸

Intrinsic and extrinsic factors have been described when determining the etiology of a stress fracture (Table 1). Intrinsic factors consist of the patient's anatomy and biology including cavus feet, leg length discrepancies, excessive forefoot varus tarsal coalitions, a prominent posterior calcaneal process, tight heel cords, poor bone density or vascular supply, and abnormal hormonal levels.^{35,46,55} Extrinsic factors such as type

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Table 1. Intrinsic and extrinsic factors related to stress fractures of the foot and ankle^{34,44,51}

Intrinsic Factors	Extrinsic Factors
Cavus feet	Type of activity
Leg length discrepancies	Excessive/new training regimen
Excessive forefoot varus	Poor equipment/footwear
Tarsal coalitions	Improper technique
Prominent posterior calcaneal process	Type of training surface
Tight heel cords	Sleep deprivation
Osteopenia/osteoporosis	
Poor vascular supply	
Abnormal hormonal levels	

of activity, excessive or new training regimens, equipment and footwear issues, training surfaces and techniques, and nutrition can also play a role.^{35,46,55} Several studies have described the biomechanical effects of muscle fatigue as a possible factor in the development of stress fractures.^{96,102} Continued training after muscle fatigue changes loading patterns of the foot based on force plate studies and is postulated to be a factor in stress-related injuries.¹⁰²

Female individuals have a higher incidence of stress fractures.^{35,46,71,72,90} Anatomically, a wider pelvis and more common genu valgum results in a compensatory increased Q-angle and often foot pronation.^{5,55} On average, female individuals have 25% less muscle mass than male individuals, which can focus forces on to a smaller area of bone with less muscle protection.⁵⁵ The “female athlete triad” (eating disorder, amenorrhea, and osteoporosis) is found among competitive female athletes, particularly those involved in long-distance running, figure skating, and gymnastics.^{5,28,30,35} High-level endurance athletes from both sexes are in danger of osteoporosis based on the effects of estrogen and testosterone on bone remodeling; low levels of sex steroids have been measured following rigorous training sessions in both male and female athletes.¹⁰¹ Sex steroids normally inhibit osteoclasts and enhance osteoblasts, thereby slowing the resorption process; subphysiologic levels correlate with low bone mineral density.¹⁰¹

Two main categories, low and high (Table 2), have been used to determine the relative risk of either going on to complete fracture or to nonunion and aid in guiding the work-up and treatment of stress fractures.^{12,13,35} Low-risk stress fractures, such as those of the calcaneus, have a better prognosis and can often be diagnosed clinically and treated with activity modification.^{12,13,35} Those at high risk, such as the navicular, talus, medial malleolus, proximal fifth metatarsal, and sesamoids, will often need more advanced imaging, periods of nonweightbearing, and possibly surgical fixation.^{12,13,35}

Table 2. High- and low-risk stress fractures of the foot and ankle^{12,13,34}

High Risk	Low Risk
Medial malleolus	Calcaneus
Talus	Cuboid
Navicular	Cuneiforms
Fifth metatarsal base	Lateral malleolus
Sesamoid	

HISTORY, PHYSICAL EXAMINATION, AND IMAGING

Patients typically present with a progressive onset of pain with weightbearing activity over a period of days to weeks.⁴³ History may include a rapid increase in mileage, intensity, or duration of activity; changes in playing surface or sport or inadequate rest periods should raise the suspicion of a stress fracture.^{8,12,13,18,35,46,55,58,62,63,90,96} A thorough history including diet, nutrition, medications, daily activities, footwear, and menstrual cycles in female athletes should be discussed.^{5,8,12,13,24,35,46,90} On physical examination, pain with weightbearing or range of motion of a joint near a stress fracture may be elicited, point tenderness is almost universal, and in more superficial areas, edema, warmth, ecchymosis, or even a palpable callus may be present.^{8,12,13,18,35,46,55,58,62,63,90,96} Assessment of limb alignment and length discrepancies, gait, passive range of motion, tendon function, and callosities provides information about repetitive stresses placed on the symptomatic area.¹⁶ Noting alignment of the ankle in neutral, cavovarus, or planovalgus and determining fixed or flexible deformities can provide insight into the

underlying causes of the pathology.¹⁶ Stiff joints as well as ligamentous laxity are a sign of improper forces across a joint, postulated to put the patient at higher risk of stress fracture.¹⁶

Imaging studies including radiographs, computed tomography (CT) scans, MRI, and bone scintigraphy can be helpful when the diagnosis is questionable or stress fracture is suspected in a high-risk bone given the possible sequelae of a missed or late diagnosis.¹² Plain films will often be negative for the first 2 weeks following a stress fracture, until resorption, sclerosis, or callus formation occurs.^{12,13} Radionuclide bone scan has been shown to be a sensitive imaging modality since the 1970s.^{12,78,81} Changes can be seen within 48 to 72 hours of injury.⁸¹ Uptake in all 3 phases of a technetium-99m diphosphonate scan is characteristic of a stress reaction/fracture and can be differentiated from soft tissue injury, which will only show increased uptake in the first phase (angiographic and blood pool/soft tissue imaging, respectively).⁸¹ MRI has replaced bone scan as the imaging modality of choice in many settings and gives superior specificity and resolution over bone scintigraphy.⁷³ CT scan can be used to identify incomplete and complete fractures but cannot aid in identification of stress reactions.⁷³ However, CT scan is thought to be more helpful than MRI in following the healing of stress fractures.⁹¹ Burne et al¹⁹ proposed that as a stress fracture heals, the initial edema and hematoma seen well on MRI for diagnosis is replaced by sclerosis, which is better seen on CT scan. This, in combination with a thick periosteum in some locations, impairs the ability of MRI to pick up some subtle fracture lines.⁹¹ Therapeutic ultrasound can also be used as an adjunct to the physical examination. Although previously thought to have poor sensitivity and specificity, a recent trial found increased pain with the application of therapeutic ultrasound at the site of a stress injury to have a positive predictive value of 99% (sensitivity, 81.9%; specificity, 66.6%).⁷⁷

HIGH-RISK STRESS FRACTURES

Some foot and ankle stress fractures have a relatively low propensity for spontaneous healing due to various factors such as blood supply, shearing forces across their surface, and location.^{12,35,46} Strict nonweightbearing, immobilization, and, not uncommonly, surgery are frequently needed to obtain a solid union.^{12,35,46}

Medial Malleolus

Stress fractures of the medial malleolus are uncommon and generally found in athletes involved in running, jumping, and kicking sports, although abnormal forces at the ankle due to tibial and talar osteophytes have also been implicated.^{42,89,91} The first series of 6 patients reported by Shelbourne in 1988 described medial malleolar tenderness, ankle effusion, pain during running activities, and a vertical radiolucent line extending from the plafond on radiographs.⁹¹ Although most medial malleolar stress fractures occur in skeletally mature patients, adolescent cases have been reported.⁸⁹

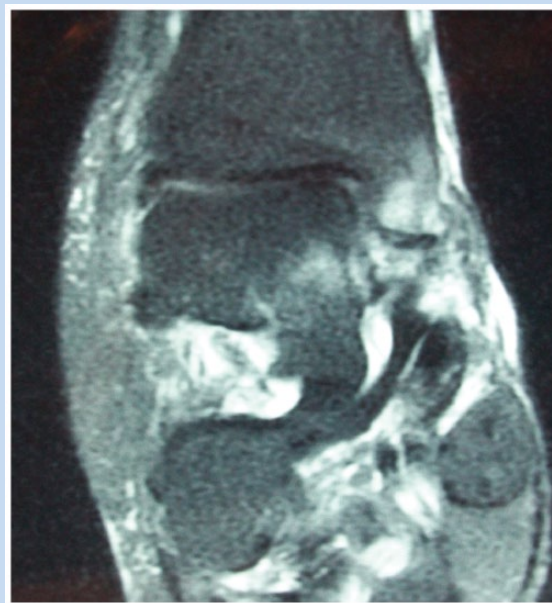


Figure 1. T2-weighted MRI showing high signal in the medial malleolus.

A patient with concerning symptoms but negative radiographs should undergo a bone scan or MRI (Figure 1). An incomplete fracture on MRI or a positive bone scan can be treated with cast immobilization and nonweightbearing.^{75,89,91} Although most of these injuries will heal with appropriate nonoperative treatments, internal fixation may be considered to allow earlier return to competitive sports, often within 1 to 2 months.^{52,75,89,91} Several series of medial malleolar stress fractures in athletes showed that both time to healing and return to sport were longer in the nonoperative group.⁸⁹

Talus

Talar stress fractures were first described in 1965 by McGlone.⁶⁰ It is a relatively rare injury; athletes and military recruits performing repetitive axial loading activities are most prone to this injury.^{82,93,94} Advanced imaging, particularly MRI, is often required to obtain a diagnosis (Figure 2).^{14,93,94} Physical examination findings are variable, including point tenderness, ankle effusion, or soft tissue swelling.^{14,60,93,94} Excessive subtalar pronation or plantar flexion is noted clinically in many patients with lateral process stress injuries due to impingement of the lateral process of the calcaneus on the posterolateral talus.¹⁴ The superior part of the talar head is most frequently involved, and the posterolateral talar body fracture will usually be seen extending into the subtalar joint.^{14,93}

A retrospective review of Finnish military recruits found 56 talar stress injuries (reactions and fractures). Five patients had bilateral injuries, and 44 had other associated lower extremity stress injuries. Sixty-seven percent were in the talar head, 25%

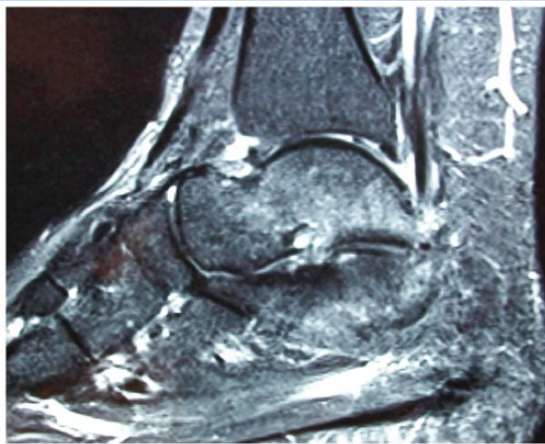


Figure 2. T2-weighted MRI showing high signal in the talus.

in the body, and 8% in the posterior portion, similar to previous reports.⁹³ Talar head injury was associated with navicular stress injury, upper talar body with calcaneal injury, and posterior talus with posterior impingement and a symptomatic os trigonum.⁹³ Patients treated nonoperatively (NSAIDs, relative rest, partial weightbearing as tolerated) until asymptomatic did well, with a mean duration of treatment of 64 days.⁹⁴ In contrast, others recommended a minimum of 6 weeks of nonweightbearing for this injury due to concern for delayed healing and avascular necrosis.¹⁴ There is no established treatment algorithm for talar stress fractures given the lack of scientific analysis and outcomes. Although orthotics are not used for treatment, patients with excessive pronation may benefit from orthotics to reduce lateral loading, given the coincidence of pronation and lateral talar stress fractures in some series.^{14,16}

Navicular

Navicular stress fractures are currently considered high risk due to the rate of nonunion.^{12,35} Patients are usually involved in explosive sprinting or jumping activities and complain of pain at the dorsum of the midfoot or along the medial longitudinal arch with activity.⁹⁹ Swelling, erythema, and ecchymosis are less reliable, but point tenderness at the dorsal aspect of the navicular known as N-spot tenderness is the most consistent finding.^{12,35} Clinical suspicion should prompt radiographic evaluation, and advanced imaging should be obtained if initial radiographs are negative.^{33,99} MRI (Figure 3) and bone scan provide no additional benefit over CT.^{19,31} The fracture line usually extends from the proximal dorsal border in a plantar and distal direction in the sagittal plane.^{19,33} The central third of the navicular is a watershed area between blood supplies coming from medial and lateral vessels.⁹⁹ This may lead to slower healing of physiologic microfractures in this central area and increase the risk of a stress fracture.⁹⁹ During walking and running, this region is also subjected to shear forces from the



Figure 3. T2-weighted MRI showing high signal in the navicular.

first and second metatarsals (through the cuneiforms) along the convex surface distally and the talus at the concave surface proximally.^{33,35} Anatomical risk factors include a relatively long second metatarsal, pes cavus, metatarsus adductus, medial narrowing of the talonavicular joint, talar beaking, and limited subtalar or ankle motion.⁴⁴

Small studies have supported both nonoperative and operative treatment.^{33,35,43,87,99} Nonoperative treatment typically includes nonweightbearing in a short leg cast.^{33,35,43,87,99} Operative treatment entails open reduction and internal fixation with or without bone grafting.^{33,35,43,87,99} One of the first studies reviewing this injury found good results in patients treated with nonweightbearing in a short leg cast.⁹⁹ In a review of 86 navicular stress fractures in athletes, only 26% treated with activity modification versus 86% with nonweightbearing in a short leg cast returned to sports.⁴³ Six patients initially underwent surgical treatment, and 5 returned to sports at an average of 3.8 months. They concluded that nonweightbearing in a short leg cast was the standard of care, though acknowledged that time to return to sport was shorter with initial surgical intervention. In an evaluation of 22 patients, 11 of 13 navicular stress fractures healed with nonweightbearing in short leg cast, and 8 returned to sport at an average of 4.3 months.⁸⁷ All 9 treated with initial internal fixation, with or without bone grafting, returned to sport at an average of 3.1 months.⁸⁷ In 19 navicular stress fractures, 6 treated with

a nonweightbearing short leg cast healed and returned to sports at 4 months; all 13 undergoing open reduction internal fixation (ORIF) returned at 4.1 months.⁸⁶ In these 2 studies, they found no significant difference in outcome or time to return to sports.⁸⁶ In a recent systematic review, outcomes including radiographic healing, clinical healing, and time from onset of symptoms to return to activity were compared for 3 different treatment strategies.⁹⁸ Regimens of weightbearing, nonweightbearing in short leg cast, and surgical intervention were analyzed, with no statistically significant difference between nonweightbearing in short leg cast and surgical intervention. Weightbearing treatments were inferior in all outcome measurements. This study concluded that an initial 6 to 8 weeks of nonweightbearing in a short leg cast should be the standard of care for navicular stress fractures.⁹⁸ Despite this recommendation, it should be noted that displaced fractures may have a higher risk of nonunion and poorer outcomes even with surgical treatment.⁵⁹

Metatarsal

These stress fractures occur most frequently in the second and third metatarsals and are relatively common.^{12,13,35,46} They are considered high or low risk, depending on location.^{12,13,35,46} Common in runners, military recruits, ballet dancers, and basketball players, like most, patients will report a recent increase in training.^{1,8,12,13,16,17,21-23,29,31,32,35,38,39,46,48,55,58,62,64,67,74,77,79,85,90,97,102,104}

Forefoot pain with weightbearing, inability to toe walk, point tenderness, and swelling are present on examination.^{1,8,12,13,16,17,21-23,29,31,32,35,38,39,46,48,55,58,62,64,67,74,77,79,85,90,97,102,104}

Radiographic work-up with plain films of the foot may show callus formation about the metatarsal at around 2 weeks.^{1,12,13,16,17,22,23,29,34,38,39,46,55,58,62,67,74,85} As with other stress fractures, increased uptake on bone scan should be isolated to the affected bone; MRI (Figure 4) can differentiate between stress reaction or fracture and soft tissue abnormalities.^{35,46,85}

Distal second metatarsal stress fractures are most common.¹⁶ During walking and running, the second metatarsal assumes the highest bending strain and shear force.³⁸ The fixed bases and proximal hinged metatarsophalangeal joints create a bending moment at the proximal diaphysis during the stance phase of gait.^{38,61} A relatively long second metatarsal and an excessively mobile first ray (Morton foot) increase this force even further.^{38,55,61} Additionally women have a higher middle forefoot loading force than men.⁷⁹ These anatomical and biomechanical characteristics may play a role in the development of stress fractures.^{38,79} A recent cadaveric biomechanical study showed that both custom and semicustom orthotics decrease tension and shear strain on the second metatarsal, with custom orthotics being superior.⁶¹ Clinical studies from military recruits show benefit from orthotics.^{31,66} Treatment of established distal metatarsal stress fractures is usually initially conservative with activity modification for 6 to 8 weeks with gradual return to sports when asymptomatic.¹⁶ The addition of a stiff-soled shoe, midfoot taping, walker boot, or short leg walking cast can increase comfort.^{13,16,35}

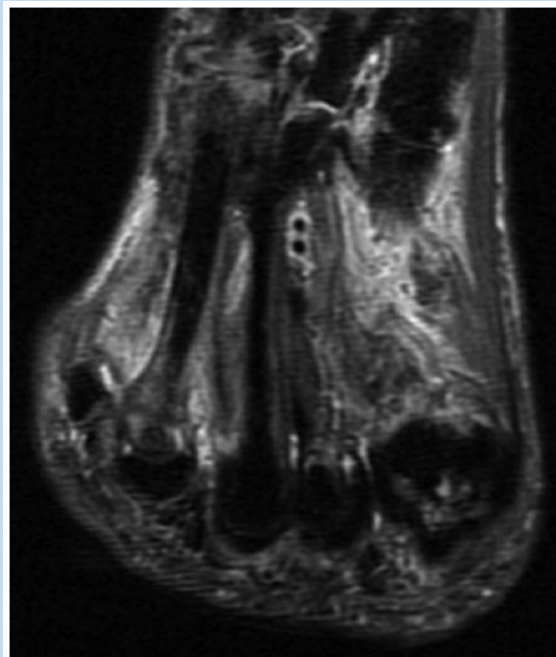


Figure 4. T2-weighted MRI showing high signal in the distal fourth metatarsal.

Second and Third Metatarsal Base

Metatarsal base stress fractures are most common in female ballet dancers.^{1,22} The insidious onset of vague midfoot pain is often overlooked or misdiagnosed.^{1,22,39,64,67,74,85} The second and third metatarsals are most at risk during ballet in the en pointe position due to the locking of the second metatarsal base and cuneiforms in extreme plantar flexion.^{1,22,39,64,67,74,85} Intrinsic risk factors include a pronated foot and poor ankle plantarflexion causing a so-called over-pointe foot with compensatory plantarflexion through the Lisfranc joint.¹ This shifts the center of gravity anterior to the metatarsal shaft, creating more force at the base. Four female ballet dancers with midfoot pain were treated successfully with a short period of immobilization and rest, and 1 required operative debridement of necrotic bone.⁶⁴ Several subsequent studies have also reported good results and return to dancing with nonoperative management, ranging from a wooden-soled shoe to short leg walking cast.^{67,74} The incidence of nonunion is low.^{22,67,85} Comorbidities including diabetes, chronic steroid use, the female athlete triad, cancer, and metabolic bone disease are associated with a higher rate of nonunion.²² Ballet trainees treated with medium energy external shock wave and ultrasound along with a period of 3 to 5 weeks of weightbearing rest had a 100% return to dancing at a mean 4.6 weeks and return to full pointe at a mean 18 days later without subsequent pain or nonunion.¹ Overall, nonsurgical management seems to yield good results with nonweightbearing or weightbearing in a regular shoe or short

leg cast.^{1,22,39,64,67,74,85} Surgical treatment of nonunion following nonoperative treatment may include drilling procedures and open reduction internal fixation.⁸⁵

Fifth Metatarsal

The typical presentation of fifth metatarsal stress fractures differs from acute fractures clinically and radiographically. Pain has usually been present for several weeks, and the fracture is classically located at the diaphyseal-metaphyseal junction.⁹⁷ Repetitive adduction force with the ankle in plantarflexion often causes these stress fractures due to the pull of the plantar fascia. As such, they are frequently seen in basketball players.^{12,29,35,77,104} A description of lateral foot pain, tenderness about the fifth metatarsal base, and pain with passive inversion stretch are clues to the diagnosis.^{12,29,35,77,104} A cavovarus foot or restricted hindfoot eversion is thought to predispose patients to fifth metatarsal base stress fractures by increasing the force on the lateral aspect of the foot.³⁵ Torg et al created a classification system for these more distal fifth metatarsal base stress fractures based on history and radiographic appearance that helps to guide treatment.⁹⁷ Type I fractures are acute fractures by history and have sharp fracture lines with no radiographic signs of healing. Type II fractures are considered delayed unions. There is no history of previous fracture, but radiographs show periosteal new bone, resorption, and sclerosis at the fracture line. Type III fractures are considered nonunions. History reveals history of pain with recurrent symptoms, likely representing repetitive insults, and on plain films, the fracture line is widened with medullary canal replaced by sclerosis. Initial treatment recommendations of nonweightbearing in a short leg cast for Type I injuries and curettage and bone grafting for Type II and III injuries were based on Torg's experience with 46 fractures.⁹⁷ Operative treatment has yielded good results using an intramedullary malleolar screw, and tension band wiring has been used with similar outcomes.^{29,51} Placement of these screws can be technically challenging as the surgeon inserts a straight screw into the curved proximal metatarsal. Intraoperative fracture of the metatarsal shaft, bicortical penetration, and skin irritation proximally are potential complications of intramedullary fixation. Seven to 10 weeks postoperatively is a reasonable goal for return to full sport activity following screw fixation and has led to screw fixation for not only Torg Type II and III, but also Type I for a faster return to sports.^{29,77} Curettage and bone grafting in addition to screw fixation is also an option for Type II and III surgical treatment.^{12,35} In a study of elite athletes, a plantar gapping of the fracture of >1 mm increases time to union (71 vs 126 days) postsurgical fixation.⁵⁰ Currently, it is recommended that Type I injuries undergo a 6- to 8-week trial of nonweightbearing in a short leg cast and Type II and III injuries undergo surgical fixation.^{77,97} An exception is a high-level athlete who wishes to return to sport sooner, in which case surgical fixation of an acute stress fracture may be considered.⁷⁷ These patients must be warned though that refracture in spite of

intramedullary fixation is possible, and returning too soon is a risk factor.^{48,104} Functional bracing or orthotics upon return to sports may reduce the high rate of refracture seen in that series.^{48,104}

Sesamoid

The medial sesamoid is more commonly injured because of its position directly under the first metatarsal head.⁹ Activities involving repetitive, forceful dorsiflexion of the toes are most commonly associated.^{9,16} Swelling or even bulging soft tissues may be present, and pain is reproduced with forced dorsiflexion.^{9,16} Radiographic differential includes bipartite sesamoid, which is difficult to distinguish on plain films but is seen in 5% to 30% of the general population.^{9,16} Sagittal cuts on CT scan may be superior to MRI or bone scan when advanced imaging is needed.⁹ Initial treatments include shoe modification, immobilization, cessation of sport, partial or nonweightbearing, systemic anti-inflammatories, and steroid injections.^{9,16,76,100} Operative treatment including sesamoidectomy,^{88,100} partial sesamoidectomy,^{9,80} closed reduction and percutaneous screw placement,¹¹ curettage, and bone grafting³ with success rates of 90% to 100% union and 100% return to sports.^{3,9,11,80,88,100} Surgical complications include hallux valgus and flexor hallucis brevis tendon dysfunction, so careful dissection of the sesamoid out of the flexor tendon sheath is important.^{9,76,88,100}

LOW-RISK STRESS FRACTURES

Low-risk stress fractures of the foot include those of the calcaneus cuboid, cuneiform bones, and the lateral malleolus, each of which usually heals with nonoperative management.^{13,16,18,21,35,46,57,58,63,105} Low-risk stress fractures of the foot are common in patients undergoing new occupations or physical training regimens involving repetitive motion.^{13,18,58,62,63}

Calcaneus

The incidence of calcaneal stress fractures is highest in military recruits and long-distance runners.^{35,40,95,106} A positive calcaneal compression test with some amount of swelling is usually present.^{35,40,49,103} The diagnosis is often missed initially because of similarity to plantar fasciitis, Baxter nerve entrapment and insertional achilles tendonitis, atrophic heel pad and retrocalcaneal bursitis, and in adolescents, Sever disease or calcaneal apophysitis.³⁵ Plain films will often show a sclerotic or radiolucent line after 2 to 3 weeks of symptoms, and a bone scan or MRI could be helpful to rule out soft tissue diagnoses (Figure 5).^{35,95,106} Calcaneal stress fractures can be adequately treated with activity modification without casting or surgical intervention.^{40,49,103} In a more recent Finnish military study of 34 stress injuries (reactions and fractures), 65% were associated with talar, cuboid, or navicular stress injuries. Nonoperative management was used in all patients; recruits were asymptomatic at an

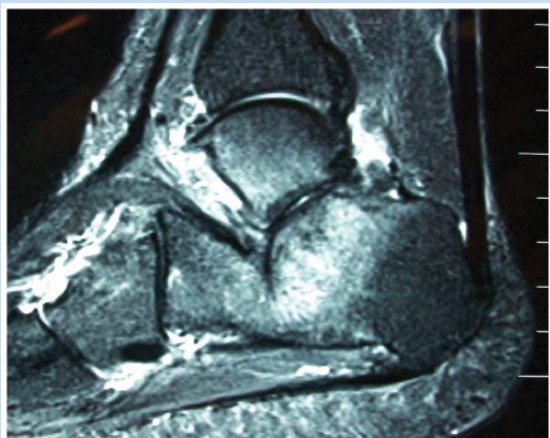


Figure 5. T2-weighted MRI showing high signal in the calcaneus.

average of 77 days. They concluded that these injuries can be treated nonoperatively with suspension from activity only.¹⁰⁶

Cuneiforms, Cuboid, Lateral Malleolus

Cuneiform stress fractures were first reported in 1936 as a march fracture of the medial cuneiform.^{18,62,63} Stress fractures of the middle and lateral cuneiform have also been reported.^{21,63} Unlike bones with a diaphysis, the cuneiform and cuboid may not display the usual periosteal callus.^{18,62,63} Instead, stress fractures may appear as a transverse sclerotic zone.^{18,62,63} MRI is the imaging of choice if plain films are unremarkable.¹⁸ These injuries will demonstrate the fracture line with bone marrow edema on both T2- and T1-weighted images.^{13,18,35,62}

The 2 forces responsible for cuneiform stress fractures are bending and compression.^{18,63} Bending forces are applied across the cuneiforms due to their location in the midfoot. The medial cuneiform lies in the axis of the first metatarsal and is susceptible to compression-type stress fractures.^{18,63} Body weight passes through this axis, and muscular insertions on each side of the first cuneiform exert strong opposing forces across a small area.^{18,63} The lateral cuneiform is the keystone of the arch with 6 articulations leading to several force vectors across this bone.^{18,63}

The mainstay of treatment of low-risk stress fractures is nonoperative.^{13,35,46,58,62,63} Initially, partial weightbearing from 2 to 6 weeks with or without immobilization is recommended until pain has abated during weightbearing activities.^{13,35,46,58,63}

OTHER TREATMENTS

Bisphosphonates

Bisphosphonates have the potential to decrease the incidence of stress fractures by decreasing bone turnover by inhibiting osteoclast function.^{4,32,65} However, a prospective, randomized trial of 324 military recruits showed no difference in the incidence of stress fractures of the lower extremities between

those receiving prophylactic risedronate and placebo.⁶⁵ There was a trend toward a harmful effect of alendronate treatment in an animal study, possibly due to inhibition of remodeling of microfractures from woven to lamellar bone.⁴ The 25-year experience of the Israeli Army on prevention of stress fractures showed sleep minimums and training modifications, but not bisphosphonate treatment, decreased the incidence of stress fractures.³²

Bone Stimulators

There are 2 types of stimulators, electromagnetic stimulators and ultrasound stimulators.

Electromagnetic stimulators generate electromagnetic fields with coils on either side of the fracture.¹⁵ Mechanical stresses cause fluid flow around and through bones that induces electrical currents around cells, which can open calcium channels in cell membranes increasing calmodulin, thus increasing cell proliferation.¹⁵ Very few controlled studies are available that evaluate the efficacy of these stimulators in stress fractures. One such study found no significant difference in time to healing between placebo and those using an electromagnetic stimulator.⁶ However, when higher grade stress fractures were compared exclusively, there was significantly shorter time to healing noted, though power was not sufficient to draw conclusions.⁶ When compliance was adequate, electromagnetic stimulators correlated to shorter healing time.⁶ Despite some early promising results, electromagnetic stimulators have not been shown conclusively to enhance healing in stress fractures.

Pulsed ultrasound bone stimulators can increase vascular endothelial growth factor (VEGF) and fibroblast growth factor (FGF), which promote angiogenesis, and increase alkaline phosphatase, bone sialoprotein, and intracellular calcium (markers of bone metabolism).⁴⁵ Most studies report on acute fractures. A systematic review of pulsed ultrasound showed low to moderate grade evidence for a positive effect: there was a 33.6% decrease in radiographic healing time.²⁰ Stress fractures may respond differently to pulsed ultrasound because they heal through intramembranous remodeling instead of endochondral remodeling as acute fractures do. Literature specifically on stress fractures treated with pulsed ultrasound is sparse.^{53,83} In a military study of 43 tibial shaft stress fractures, there was no significant difference in time to healing using low-intensity pulsed ultrasound.⁸³ In a rat ulnar stress fracture model, low-intensity pulsed ultrasound alone produced better results than ultrasound and NSAIDs combined as well as controls.⁵³

Oral Contraceptives

Low levels of sex steroids are associated with low bone mineral density.^{26,101} Abnormally low levels of sex hormones are seen for 24 to 48 hours in endurance athletes following rigorous training sessions, and secondary amenorrhea causes a hormone deficient state.^{26,101} Hormone replacement therapy

via oral contraceptive pills (OCPs) is controversial. Data suggest that hormone replacement in amenorrheic women and endurance athletes improves bone mineral density.²⁵⁻²⁷ A randomized study of 150 young female runners with low-dose OCP or no treatment showed that oligo- and amenorrheic runners who used OCPs gained 1% bone mineral density (BMD) per year.²⁴ Stress fracture incidence trended lower in the OCP group, but was not significant. A military study of female recruits found a fivefold increase in lower extremity stress fractures in women who had been amenorrheic, though OCP use did not have a significant protective effect.¹⁰⁰

If OCPs are used in exercise-induced hypoestrogenic amenorrhea, other factors such as nutrition status or other hypothalamic perturbations should be worked up and may require treatment, as energy status, calcium intake, and body mass index have proven to be independent predictors of improved BMD and normal bone turnover.^{24,25,34}

Calcium and Vitamin D

Calcium and vitamin D can improve BMD but are not definitively proven to prevent stress fractures.^{8,23,24,47,68,72,84} In track and field athletes and military recruits, no significant difference was found with increased calcium and vitamin D intake and incidence of all types of stress fractures.⁸ One of the largest studies on the topic showed that in female military recruits, 2000 mg of calcium and 800 IU of vitamin D daily had a 20% lower incidence of stress fractures during basic training than those taking a placebo.⁴⁷ Another group found that each cup of skim milk consumed daily by female distance runners lowered the rate of stress fracture by 62%.⁷² These reports support several previous studies suggesting that low dietary calcium and vitamin D is associated with increased risk of stress fracture, and adequate intake or supplementation can reduce the risk of stress fractures.^{68,94} The recommended daily dose of calcium depends on age, while vitamin D intake is more controversial.^{2,37,69,70} A specific amount of calcium and vitamin D needed to prevent stress fractures has not been determined. In some studies, daily supplementation of 500 to 800 mg of calcium and 400 to 800 IU vitamin D improves BMD and decreases fracture (not specifically stress fracture) risk significantly.^{10,36}

Calcitonin

Calcitonin inhibits osteoclasts, the offending agent in the imbalanced remodeling process of stress fractures.^{40,41,54,56} Increased BMD and biomechanical properties has been shown with calcitonin, but its role in stress fracture prevention or healing is controversial.^{40,41,54,56}

Orthotics

Several biomechanical studies have shown predictable, repetitive stress patterns in the foot and ankle with weightbearing.^{61,79} However, there is inconclusive data to support orthotics for prevention of stress fractures of the foot and ankle.^{31,32,66,92} A systematic review of 5 articles on orthotics and stress fractures concluded that orthotic use reduced the overall rate of stress fractures of the proximal femur and tibia in military personnel; no conclusion could be made regarding prevention in stress fractures of the foot and ankle.⁹²

CONCLUSION

Stress fractures of the foot and ankle in athletes are relatively uncommon at 1% of all athletic injuries.¹² However, a heightened awareness of this condition by coaches, athletic trainers, therapists, and physicians along with more rigorous training has contributed to an increasing incidence of stress fractures.⁵⁵ A change in training conditions, such as increased time or distance, new impact activities, training surface, technique, and poor nutrition, is a contributing factor in the development of stress fractures.³⁵ Additionally, in the female athletic population, coaches, athletes, and families should be educated and alerted to the adverse effects of eating disorders and hormonal abnormalities.^{5,24,26,101} The type of injury (high and low risk) as well as the demands of the patient will drive nonoperative versus operative treatment.^{12,13,35} There are mixed results with bone stimulators,^{6,7,20,45,53,83} bisphosphonates,^{4,32,65} hormone replacement,^{24-27,90,101} and dietary supplementation of calcium and vitamin D^{8,48,68,72,84} for prevention or treatment of stress fractures of the foot and ankle. There are no data to support or refute the use of calcitonin.



Clinical Recommendations

SORT: Strength of Recommendation Taxonomy

A: consistent, good-quality patient-oriented evidence

B: inconsistent or limited-quality patient-oriented evidence

C: consensus, disease-oriented evidence, usual practice, expert opinion, or case series

Clinical Recommendation	SORT Evidence Rating
Strength of recommendation taxonomy.	B
Navicular stress fractures should be treated initially with nonweightbearing. ^{33,35,43,87,99}	B
Nonoperative treatment of talar stress fractures with partial weightbearing to tolerance is effective. ⁹³	B

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