

Bone Stress Injuries in the Military: Diagnosis, Management, and Prevention

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Abstract

Bone stress injuries occur when forces applied to a bone for an extended period exceed the ability of the bone to adequately remodel. These injuries, which range from stress reactions to nondisplaced and even displaced fractures, most often affect people who experience high levels of repetitive stress and loading in the lower extremity or changes in physical activity level. For example, stress fractures are common in endurance athletes, in athletes engaged in preseason and early-season conditioning, and in military recruits. In the military, these injuries are most often encountered during basic training, when new recruits undergo the rigors of intense physical activity to which they may not be accustomed. Female athletes and athletes with poor nutritional status are at elevated risk for injury.

Bone stress injuries are difficult to diagnose

with radiographs alone. Making the correct diagnosis may require a combination of physical examination, advanced imaging, and an index of suspicion. Differences in injury location account for variations in risk for nonunion, displacement, and other complications. For low-risk injuries, treatment typically consists of reduced weight-bearing for several weeks with gradual return to activity. Higher-risk injuries need to be closely monitored for progression and may require operative intervention. Even after surgery, some types of stress fractures may take several months to achieve radiographic union. In addition, underlying nutritional or metabolic deficiencies may need to be treated to prevent future injuries.

In this article, we review the diagnosis, management, and prevention of bone stress injuries with a focus on more serious manifestations, such as stress fracture.

Bone stress injuries, which are common in military recruits, present in weight-bearing (WB) areas as indolent pain caused by repetitive stress and microtrauma. They were first reported in the metatarsals of Prussian soldiers in 1855.¹ Today, stress injuries are increasingly common. One study estimated they account for 10% of patients seen by sports medicine practitioners.² This injury most commonly affects military members, endurance athletes, and dancers.³⁻⁵ Specifically, the incidence of stress fractures in military members has been reported to range from 0.8% to 6.9% for men and from 3.4% to 21.0% for women.⁴ Because of repetitive vigorous

lower extremity loading, stress fractures typically occur in the pelvis, femoral neck, tibial shaft, and metatarsals. Delayed diagnosis and the subsequent duration of treatment required for adequate healing can result in significant morbidity. In a 2009 to 2012 study of US military members, Waterman and colleagues⁶ found an incidence rate of 5.69 stress fractures per 1000 person-years. Fractures most frequently involved the tibia/fibula (2.26/1000), followed by the metatarsals (0.92/1000) and the femoral neck (0.49/1000).⁶ In addition, these injuries were most commonly encountered in new recruits, who were less accustomed to the high-volume, high-intensity

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training required during basic training.^{4,7} Enlisted junior service members have been reported to account for 77.5% of all stress fractures.⁶ Age under 20 years or over 40 years and white race have also been found to be risk factors for stress injury.⁶

The pathogenesis of stress injury is controversial. Stanitski and colleagues⁸ theorized that multiple submaximal mechanical insults create cumulative stress greater than bone capacity, eventually leading to fracture. Johnson⁹ conducted a biopsy study and postulated that an accelerated remodeling phase was responsible, whereas Friedenberg¹⁰ argued that stress injuries are a form of reduced healing, not an attempt to increase healing, caused by the absence of callous formation in the disease process.

Various other nonmodifiable and modifiable risk factors predispose military service members to stress injury. Nonmodifiable risk factors include sex, bone geometry, limb alignment, race, age, and anatomy. Lower extremity movement biomechanics resulting from dynamic limb alignment during activity may be important. Cameron and colleagues¹¹ examined 1843 patients and found that those with knees in $>5^\circ$ of valgus or $>5^\circ$ of external rotation had higher injury rates. Although variables such as sex and limb alignment cannot be changed, proper identification of modifiable risk factors can assist with injury prevention, and nonmodifiable risk factors can help clinicians and researchers target injury prevention interventions to patients at highest risk.

Metabolic, hormonal, and nutritional status is crucial to overall bone health. Multiple studies have found that low body mass index (BMI) is a significant risk factor for stress fracture.^{7,12,13} Although low BMI is a concern, patients with abnormally high BMI may also be at increased risk for bone stress injury. In a recently released consensus statement on relative energy deficiency in sport (RED-S), the International Olympic Committee addressed the complex interplay of impairments in physiologic function—including metabolic rate, menstrual function, bone health, immunity, protein synthesis, and cardiovascular health—caused by relative energy deficiency.¹⁴ The committee stated that the cause of this syndrome is energy deficiency relative to the balance between dietary energy intake and energy expenditure required for health and activities of daily living, growth, and sporting activities. This finding reveals that conditions such as stress injury often may represent a much broader systemic deficit that may be influenced

by a patient's overall physiologic imbalance.

Diagnosis

History and Physical Examination

The onset of stress reaction typically is insidious, with the classic presentation being a new military recruit who is experiencing a sudden increase in pain during physical activity.¹⁵ Pain typically is initially present only during activity, and is relieved with rest, but with disease progression this evolves to pain at rest. It is crucial that the physician elicit the patient's history of training and physical activity. Hsu and colleagues⁷ reported increased prevalence of overweight civilian recruits, indicating an increase in the number of new recruits having limited experience with the repetitive physical activity encountered in basic training. Stress injury should be suspected in the setting of worsening, indolent lower extremity pain that has been present for several days, especially in the higher-risk patient populations mentioned. Diet should be assessed, with specific attention given to the intake of fruits, vegetables, and foods high in vitamin D and calcium and, most important, the energy balance between intake and output.¹⁶ Special attention should also be given to female patients, who may experience the female athlete triad, a spectrum of low energy availability, menstrual dysfunction, and impaired bone turnover (high amount of resorption relative to formation). A key part of the RED-S consensus statement¹⁴ alerted healthcare providers that metabolic derangements do not solely affect female patients. These types of patients sustain a major insult to the homeostatic balance of the hormones that sustain adequate bone health. Beck and colleagues¹⁷ found that women with disrupted menstrual cycles are 2 to 4 times more likely to sustain a stress fracture than women without disrupted menstrual cycles, making this abnormality an important part of the history.

Examination should begin with careful evaluation of limb alignment and specific attention given to varus or valgus alignment of the knees.¹¹ The feet

Take-Home Points

- Stress injuries, specifically of the lower extremity, are very common in new military trainees.
- Stress injury can range from benign periosteal reaction to displaced fracture.
- Stress injury should be treated on a case-by-case basis, depending on the severity of injury, the location of the injury, and the likelihood of healing with nonoperative management.
- Modifiable risk factors such as nutritional status, training regiment, and even footwear should be investigated to determine potential causes of injury.
- Prevention is a crucial part of the treatment of these injuries, and early intervention such as careful pre-enrollment physicals and vitamin supplementation can be essential in lowering injury rates.



Figure 1. In the fulcrum test, the patient's thigh is placed on the examiner's thigh, axial load is applied to either side, and pain is reproduced in the event of a stress fracture.



Figure 2. Plain radiograph shows fifth metatarsal stress fracture (blue arrow), not yet violating both cortices.

should also be inspected, as pes planus or cavus foot may increase the risk of stress fracture.¹⁸ Identification of the area of maximal tenderness is important. The area in question may also be erythematous or warm secondary to the inflammatory response associated with attempted fracture healing. In chronic fractures in superficial areas such as the metatarsals, callus may be palpable. Although there are few specific tests for

stress injury, pain may be reproducible with deep palpation and WB. If a femoral fracture is suspected, the fulcrum test can be performed by applying downward pressure on the patient's knee while levering the thigh over the examiner's opposite arm or thigh (**Figure 1**).¹⁹ Patients with sacral stress fractures may have pain when standing or hopping on the affected side (positive flamingo test).²⁰

Laboratory Testing

When a pathology is thought to have a nutritional or metabolic cause, particularly in a low-weight or underweight patient, a laboratory workup should be obtained. Specific laboratory tests that all patients should undergo are 25-hydroxyvitamin D3, complete blood cell count, and basic chemistry panel, including calcium and thyroid-stimulating hormone levels. Although not necessary for diagnosis, phosphate, parathyroid hormone, albumin, and prealbumin should also be considered.

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Females should undergo testing of follicle stimulating hormone, luteinizing hormone, estradiol, and testosterone and have a urine pregnancy test. In patients with signs of excessive cortisone, a dexamethasone suppression test can be administered.²¹ In males, low testosterone is a documented risk factor for stress injury.²²

Imaging

Given their low cost and availability, plain radiographs typically are used for initial examination of a suspected stress injury. However, they often lack sensitivity, particularly in the early stages of stress fracture development (**Figure 2**). Although a fracture line or callus formation is present occasionally, findings may be subtler. Images should be inspected for blunting of cortical bone and periosteal reaction, which should be correlated with the site of maximal tenderness.¹¹ When there is high clinical suspicion based on history and physical examination, but radiographs are negative, magnetic resonance imaging (MRI) or bone scan can be useful.²³ MRI is the most accurate imaging modality, with sensitivity ranging from 86% to 100% and specificity as high as 100%.^{2,24,25} On MRI, stress fractures typically are seen as bright areas of increased edema. Arendt and Griffiths²⁴ proposed an MRI-based grading system for stress fractures, with grades 1 and 2 representing low-grade injuries, and 3 and 4 representing high grade. Computed tomography (CT) also has a role in diagnosis and may be better than MRI in imaging stress fractures in the pelvis and sacrum.² In a study involving tibial stress fractures, Gaeta and colleagues²⁶ found MRI was 88% sensitive and 100% specific and had a positive predictive value of 100%, and CT was 42% sensitive and 100% specific and had a positive predictive value of 100%. They concluded MRI was superior to CT in the diagnosis of tibial stress fractures.

Management

Management of bone stress injury depends on many factors, including symptom duration, fracture location and severity, and risk of progression or nonunion (**Table**).¹³ Patients thought to have an underlying metabolic or nutritional derangement should be treated accordingly. Injuries with a low risk of nonunion or further displacement typically can be managed with a period of modified physical activity or reduced or non-WB (NWB) ambulation; higher risk injuries may require operative intervention.⁵

Pelvis

Pelvic stress fractures are rare and represent only 1.6% to 7.1% of all stress fractures.^{13,27,28} Given the low frequency, physicians must have a high index of suspicion to make the correct diagnosis. These fractures typically occur in marathon runners and other patients who present with persistent pain and a history of high levels of activity. As pelvic stress fractures typically involve the superior or inferior pubic rami, or sacrum, and are at low risk for nonunion,¹³ most are managed with nonoperative treatment and activity modification for 8 to 12 weeks.²⁷

Femur

Femoral stress fractures are also relatively uncommon, accounting for about 10% of all stress fractures. Depending on their location, these fractures can be at high risk for progression, nonunion, and significant morbidity.²⁹ Especially concerning are femoral neck stress fractures, which can involve either the tension side (lateral cortex) or the compression side (medial cortex) of the bone. Suspicion of a femoral neck stress fracture should prompt immediate NWB.⁵ Early recognition of these injuries is crucial because once displacement occurs, their complication and morbidity rates become high.¹³ Patients with compression-side fractures should undergo NWB treatment for 4 to 6 weeks and then slow progression to WB activity. Most return to light-impact activity by 3 to 4 months. By contrast, tension-side fractures are less likely to heal without operative intervention.¹¹ All tension-side fractures (and any compression-side fractures >50% of the width of the femoral neck) should be treated with percutaneous placement of cannulated screws (**Figure 3**). Displaced fractures should be addressed urgently with open reduction and internal fixation to avoid avascular necrosis and other long-term sequelae.⁵ Results of operative treatment of femoral neck fractures in active individuals have been mixed. Neubauer and colleagues³⁰ examined 48 runners who underwent surgical fixation for these injuries. Preinjury activity levels were resumed by a higher percentage of low-performance runners (72%, 23/32) than low-performance runners (31%, 5/16). Reporting on femoral neck stress fracture outcomes in Royal Marine recruits, Evans and colleagues³¹ found that, after operative intervention, all fractures united by 11 months on average. However, union in 50% of fractures took more than 1 year, revealing the difficulty in managing these

Table. **Injuries With High and Low Risk of Nonunion**^{11,13,25}

High Risk	Low Risk
Lateral femoral neck	Pelvis (rami, sacrum)
Femoral head	Medial femoral neck
Anterior tibial shaft	Femoral shaft
Patella	Posteromedial tibial shaft
Medial malleolus	Fibula
Second metatarsal base	Third and fourth metatarsals
Fifth metatarsal	Cuboid
Sesamoids	Calcaneus
Navicular	Cuneiform
Talus	

injuries as well as the lengthy resulting disability.

Stress fractures of the femoral shaft are less common than those of the femoral neck and represent as little as 3% of all stress fractures.³² However, femoral shaft stress fractures are more common in military populations. In French military recruits, Niva and colleagues³³ found an 18% incidence. Similar to femoral neck fractures, femoral shaft fractures typically are diagnosed with advanced imaging, though the fulcrum test and pain



Figure 3. T2-weighted magnetic resonance imaging shows a femoral neck stress fracture (blue arrow). Fracture begins at the medial cortex (compression side of the femoral neck) but involves >50% of the femoral neck, putting it at high risk for displacement. Typical treatment is surgery.



Figure 4. In tibial stress injuries, the point of maximal tenderness is often on the posteromedial cortex.



Figure 5. Lateral radiograph shows a stress fracture with stress reaction of the anterior tibial cortex (blue arrow).

on WB can aid in the diagnosis.¹⁹ These injuries are often managed nonoperatively with NWB for a period. Weishaar and colleagues³⁴ described US military cadets treated with progressive rehabilitation who returned to full activity within 12 weeks. Displaced femoral shaft fractures associated with bone stress injury are even less common, and should be managed operatively. Salminen and

colleagues³⁵ found an incidence of 1.5 fractures per 100,000 years of military service. Over a 20-year period, they surgically treated 10 of these fractures. Average time from intramedullary nailing to union was 3.5 months.

Tibia

The tibia is one of the more common locations for stress injury and fracture. In a prospective study with members of the military, Giladi and colleagues³⁶ found that 71% of stress fractures were tibia fractures. In addition, a large study of 320 athletes with stress fractures found 49.1% in the tibia.³⁷ Fractures typically are diaphyseal and transverse, usually occurring along the posteromedial cortex, where the bone experiences maximal compressive forces (**Figure 4**).^{5,13} Fractures on the anterior cortex—thought to result from tensile forces applied by the large posterior musculature of the gastrocnemius during repetitive activity³⁸—are more concerning. Compared with fractures on the compression side, fractures of the anterior tibial cortex are at higher risk for nonunion (reported nonunion rate, 4.6%).³⁹ Radiographs of anterior tibial cortex fractures may show the “dreaded black line” (**Figure 5**).

Compression-side fractures often heal with nonoperative management, though healing may take several months. Swenson and colleagues⁴⁰ studied the effects of pneumatic bracing on conservative management and return to play in athletes with tibial stress fractures. Patients with bracing returned to light activity within 7 days and full activity within 21 days, whereas those without bracing returned to light activity within 21 days and full activity within 77 days. Pulsed electromagnetic therapy is of controversial benefit in the management of these injuries. Rettig and colleagues⁴¹ conducted a prospective randomized trial in the treatment of US Navy midshipmen and found no reduction in healing time in those who underwent electromagnetic therapy. Stress fractures with displacement and fractures that have failed nonoperative treatment should undergo surgery. Reamed intramedullary nailing is the gold standard of operative management of these injuries.⁵ Varner and colleagues⁴² reported the outcomes of treating 11 tibial stress fractures with intramedullary nailing after nonoperative management (4 months minimum) had failed. With surgery, the union rate was 100%, and patients returned to full activity by a mean of 4 months.

Metatarsals

Stress fractures were first discovered by Briethaupt¹ in the painful swollen feet of Prussian army members in 1855 and were initially named *march fractures*. Waterman and colleagues⁶ reported that metatarsal stress fractures accounted for 16% of all stress fractures in the US military between 2009 and 2012. The second metatarsal neck is the most common location for stress fractures, followed by the third and fourth metatarsals, with the fifth metatarsal being the least common.⁵ The second metatarsal is thought to sustain these injuries more often than the other metatarsals because of its relative lack of immobility. Donahue and Sharkey⁴³ found that the dorsal aspect of the second metatarsal experiences twice the amount of strain experienced by the fifth metatarsal during gait, and that peak strain in the second metatarsal was further increased by simulated muscle fatigue. The risk of stress fracture can be additionally increased with use of minimalist footwear, as shown by Giuliani and colleagues,⁴⁴ particularly in the absence of a progressive transition in gait and training volume with a change toward minimalist footwear. In patients with a suspected or confirmed fracture of the second, third, or fourth metatarsal, treatment typically is NWB and immobilization for at least 4 weeks.⁵ Fifth metatarsal stress injuries (Figure 2) typically are treated differently because of their higher risk of nonunion. Patients with a fifth metatarsal stress fracture complain of lateral midfoot pain with running and jumping. For those who present with this fracture early, acceptable treatment consists of 6 weeks of casting and NWB.⁵ In cases of failed nonoperative therapy, or presentation with radiographic evidence of nonunion, treatment should be intramedullary screw fixation, with bone graft supplementation based on surgeon preference. DeLee and colleagues⁴⁵ reported on the results of 10 athletes with fifth metatarsal stress fractures treated with intramedullary screw fixation without bone grafting. All 10 experienced fracture union, at a mean of 7.5 weeks, and returned to sport within 8.5 weeks. One complication with this procedure is pain at the screw insertion site, but this can be successfully managed with footwear modification.⁴⁵

Prevention

Proper identification of patients at high risk for stress injuries has the potential of reducing the incidence of these injuries. Lappe and colleagues⁴⁶

prospectively examined female army recruits before and after 8 weeks of basic training and found that those who developed a stress fracture were more likely to have a smoking history, to drink more than 10 alcoholic beverages a week, to have a history of corticosteroid or depot medroxyprogesterone use, and to have lower body weight. In addition, the authors found that a history of prolonged exercise before enrollment was protective against fracture. This finding identifies the importance of having new recruits undergo risk factor screening, which could result in adjusting training regimens to try to reduce injury. The RED-S consensus statement¹⁴ offers a comprehensive description of the physiologic factors that can contribute to such injury. Similar to proper risk factor identification, implementation of proper exercise progression programs is a simple, modifiable method of limiting stress injuries. For new recruits or athletes who are resuming activity, injury can be effectively prevented by adjusting the frequency, duration, and intensity of training and the training loads used.⁴⁷

Vitamin D and calcium supplementation is a simple intervention that can be helpful in injury prevention, and its use has very little downside. A double-blind study found a 20% lower incidence of stress fracture in female navy recruits who took 2000 mg of calcium and 800 IU of vitamin D as daily supplementation.⁴⁸ Of importance, a meta-analysis of more than 65,000 patients found vitamin D supplementation was effective in reducing fracture risk only when combined with calcium, irrespective of age, sex, or prior fracture.⁴⁹ In female patients with the female athlete triad, psychological counseling and nutritional consultation are essential in bone health maintenance and long-term prevention.⁵⁰ Other therapies have been evaluated as well. Use of bisphosphonates is controversial for both treatment and prevention of stress fractures. In a randomized, double-blind study of the potential prophylactic effects of risedronate in 324 new infantry recruits, Milgrom and colleagues⁵¹ found no statistically significant differences in tibial, femoral, metatarsal, or total stress fracture incidence between the treatment and placebo groups. Therefore, bisphosphonates are seldom recommended as prevention or in primary management of stress fracture.

In addition to nutritional and pharmacologic therapy, activity modification may have a role in injury prevention. Gait retraining has been identified as a potential intervention for reducing stress

fractures in patients with poor biomechanics.⁴⁷ Crowell and Davis⁵² investigated the effect of gait retraining on the forces operating in the tibia in runners. After 1 month of gait retraining, tibial acceleration while running decreased by 50%, vertical force loading rate by 30%, and peak vertical force impact by 20%. Such studies indicate the importance of proper mechanics during repetitive activity, especially in patients not as accustomed to the rigorous training methods used with new military recruits. However, whether these reduced loads translate into reduced risk of stress fracture remains unclear. In addition, biomechanical shoe orthoses may lower the stress fracture risk in military recruits by reducing peak tibial strain.⁵³ Warden and colleagues⁵⁴ found a mechanical loading program was effective in enchainning the structural properties of bone in rats, leading the authors to hypothesize that a similar program aimed at modifying bone structure in humans could help prevent stress fracture. Although there have been no studies of such a strategy in humans, pretraining may be an area for future research, especially for military recruits.

Conclusion

Compared with the general population, members of the military (new recruits in particular) are at increased risk for bone stress injuries. Most of these injuries occur during basic training, when recruits significantly increase their repetitive physical activity. Although the exact pathophysiology of stress injury is debated, nutritional and metabolic abnormalities are contributors. The indolent nature of these injuries, and their high rate of false-negative plain radiographs, may result in a significant delay in diagnosis in the absence of advanced imaging studies. Although a majority of injuries heal with nonoperative management and NWB, several patterns, especially those on the tension side of the bone, are at high risk for progression to fracture and nonunion. These include lateral femoral cortex stress injuries and anterior tibial cortex fractures. There should be a low threshold for operative management in the setting of delayed union or failed nonoperative therapy. Of equal importance to orthopedic management of these injuries is the management of underlying systemic deficits, which may have subjected the patient to injury in the first place. Supplementation with vitamin D and calcium can be an important prophylaxis against stress injury. In addition, military recruits and athletes with underlying metabolic or hormonal

deficiencies should receive proper attention with a focus on balancing energy intake and energy expenditure. Stress injury leading to fracture—increasingly common in military populations—often requires a multimodal approach for treatment and subsequent prevention.

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This paper will be judged for the Resident Writer's Award.