Lower Extremity Stress Fractures in the Military

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KEYWORDS

- Stress fracture
- Military
- Recruit
- Femoral neck

KEY POINTS

- Stress fractures of the lower extremities are common among the military population and athletes.
- Modifiable risk factors include poor nutritional status, low entry-level fitness, and rapid progression of intensity and duration of exercise.
- Nonmodifiable risk factors include female sex, advanced age, and those individuals who have already sustained a stress fracture.
- Prevention is aimed at manipulating the modifiable risk factors, such as altering overall training volume and limiting distance running.
- In the soldier or athlete who presents with activity-related pain, stress fractures should be given significant consideration during the clinical evaluation.

INTRODUCTION

Stress fractures are common injuries in athletes, dancers, and military populations.1–6 These fractures can be partial or complete fractures of bone that result from repetitive microtrauma. Bone remodeling normally occurs as a balance of osteoclastic resorption and osteoblastic production in response to physiologic stress and mechanical loads. As osteoblastic activation lags behind resorption, there is a period of time when fracture risk increases because of weakened bone.7–9 Many individuals who sustain stress fractures can identify a sudden increase in workout intensity or duration as a precipitating factor for injury, and it is thought that gradual progressions in both exercise intensity and duration may reduce the risk of fracture.3 As the nation has become more sedentary and overweight in recent years, the overall fitness level of military recruits has declined.10 As a result, the rigorous physical requirements during basic combat training place the new soldier at an increased risk for sustaining several lower extremity overuse injuries; however, one of the most significant injuries

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sustained in this population is insufficiency or stress fracture. The purpose of this review is to discuss the epidemiology and pathogenesis of stress fractures with a focus on reviewing the current literature on injury prevention and the assessment, diagnosis, and clinical management of low- and high-risk stress fractures within the active-duty military population.

THE BURDEN AND PATHOGENESIS OF STRESS FRACTURE INJURIES IN PHYSICALLY ACTIVE POPULATIONS

Incidence and Impact

Lower extremity stress fracture injuries disproportionately affect athletes and military service members who regularly engage in vigorous weight-bearing physical activities. Stress fractures, particularly in high-risk regions of the proximal femur, hip, and pelvis, can lead to serious injury, morbidity, and potentially long-term disability. These injuries can also negatively impact force readiness and lead to lost training time, failure to complete training requirements, and medical discharge from military service. Service members are typically at the greatest risk for stress fracture during basic combat training and initial entry-level training. Studies have reported the cumulative incidence or incidence proportion of lower extremity stress fracture during initial entry-level military training to range from 0.8% to 6.9% for men and 3.4% to 21.0% for women. A recent large-scale population-based study reported stress fracture injury incidence during basic combat training to be 6.9 cases per 1000 recruits among men and 26.1 cases per 1000 recruits among women.

Risk factors for lower extremity stress fracture injuries have traditionally been categorized by loci into either intrinsic (individual characteristics) or extrinsic (environmental factors external to the individual) factors. However, in order to prevent lower extremity stress fractures, it is critical to identify and focus on the modifiable risk factors associated with injury. As a result, classifying risk factors by whether they are modifiable or nonmodifiable is much more relevant from a clinical and injury prevention perspective. The modifiable risk factors for lower extremity stress fractures serve as important targets for injury prevention interventions. Other risk factors may be potentially modifiable. These factors can be modified under certain circumstances but might not be modifiable under others because of resource or other constraints (eg, running routes or surfaces). Nonmodifiable risk factors are equally important for identifying individuals and populations that are at the greatest risk for injury, but these factors cannot be altered via intervention. In addition to establishing those that are most likely to sustain lower extremity stress fractures, nonmodifiable risk factors can also serve to inform screening guidelines and preventative measures, particularly in the presence of other modifiable risk factors. The modifiable, potentially modifiable, and nonmodifiable risk factors associated with lower extremity stress fracture are presented in Table 1. The remainder of this section provides an overview of the most common modifiable and nonmodifiable risk factors associated with lower extremity stress fractures.

Modifiable Risk Factors

Some of the most important modifiable risk factors for lower extremity stress fractures among individuals entering military service are poor indices of entry-level physical fitness. Many studies have demonstrated that poor entry-level aerobic fitness is associated with the subsequent risk of stress fracture, and Jones and colleagues summarized several of these studies in a systematic review. Based on data from several prospective studies, individuals with the slowest entry-level run times were 2.5 to 7.7 times as likely to experience lower extremity stress fracture injuries during basic
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<tr>
<td><strong>Entry-level Physical Fitness</strong></td>
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<tr>
<td>Lower aerobic fitness</td>
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<tr>
<td>Lower muscle strength and endurance</td>
<td>Intrinsic</td>
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<td>Poorer flexibility</td>
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<td><strong>Biomechanical Movement Patterns</strong></td>
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<tr>
<td>Greater peak hip adduction angle (gait)</td>
<td>Intrinsic</td>
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<td>Greater peak rear foot eversion angle (gait)</td>
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<tr>
<td>Increased sagittal plane knee stiffness (gait)</td>
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<td>Increased absolute free moment (gait)</td>
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<td>Increased vertical force impact peak (gait)</td>
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<td>Increased peak positive acceleration of the tibia (gait)</td>
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<td>Increased tibial shock (gait)</td>
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<td>Increased peak vertical loading rate (gait)</td>
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<td>Increased peak vertical ground reaction force (jump landing task)</td>
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<td>Increased medial ground reaction force (jump landing task)</td>
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<td>Increased knee valgus (jump landing task)</td>
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<td>Increased knee internal rotation (jump landing task)</td>
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<td><strong>Body Composition</strong></td>
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<td>Lower body mass index</td>
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<td><strong>Nutritional Factors</strong></td>
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<td>Low serum vitamin D</td>
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<td>Low calcium</td>
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<td>Poor diet and low caloric intake relative to demands</td>
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<td><strong>Other Health Risk Behaviors</strong></td>
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<td>Smoking and tobacco use</td>
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<td>Sedentary lifestyle</td>
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<td>Amenorrhea and menstrual irregularity</td>
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<td><strong>Footwear</strong></td>
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<td>Shoe type</td>
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<td>Boot type</td>
<td>Extrinsic</td>
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<td>Insoles or orthotic devices</td>
<td>Extrinsic</td>
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<td><strong>Training-Related Variables</strong></td>
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<td>Rapid progression in</td>
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<td>Training volume</td>
<td>Extrinsic</td>
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<td>Training intensity</td>
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<td>Training distance</td>
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combat training when compared with those with the fastest entry-level run times. Whether or not entry-level strength or flexibility is associated with the risk of stress fracture injuries remains unclear, as conflicting results have been reported in the literature; however, a recent prospective study suggests that knee flexor and extensor weakness may be associated with the incidence rate of lower extremity stress fractures, as this can limit the ability to dissipate force in the sagittal plane during gait and jumping tasks. Studies also show that those who lead sedentary lifestyles, or do not report regularly engaging in weight-bearing physical activities before beginning basic combat training in the military, are also at increased risk for lower extremity stress fractures. Furthermore, a rapid progression in total weight-bearing exercise volume, frequency, intensity, or duration within these individuals, as is typical during basic combat training in the military, are also at increased risk for lower extremity stress fractures during initial entry-level training. These training-related variables are all modifiable, and appropriately managing a gradual progression and increase in exercise volume can likely mitigate the risk of lower extremity stress fractures among athletes and military personnel during the early weeks of training.

Several studies have recently focused on how biomechanical movement patterns during gait and landing from a jump might be associated with the risk for lower extremity stress fractures (see Table 1). These movement patterns are important because recent studies have demonstrated that movement retraining interventions might be effective in mitigating these factors and potentially the subsequent risk for lower extremity stress fractures. Milner and colleagues reported that free moment during gait, which is a measure of torque about a vertical axis at the interface of the shoe and the ground and serves as a surrogate measure of torque acting on the tibia, was associated with a history of tibial stress fracture. In a related study, Milner and colleagues also reported that tibial stress fracture cases had significantly greater instantaneous and average vertical loading rates and tibial shock during

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<td>Potentially Modifiable Risk Factors</td>
<td>Nonmodifiable Risk Factors</td>
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<tr>
<td>Low bone mineral density</td>
<td>Female sex</td>
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<td>Type of training activity/sport</td>
<td>Increased age</td>
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<td>Training environment</td>
<td>White race</td>
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<td>Type of running surface (eg, pavement, dirt, grass, track)</td>
<td>History of lower extremity stress fractures</td>
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<td>Lower extremity morphology &amp; anatomic factors</td>
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<td>High arches in the foot</td>
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<td>Genu valgum at the knee (knock-kneed)</td>
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<td>High quadriceps angle (Q angle)</td>
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<td>Leg length discrepancy</td>
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<td>Bone geometry</td>
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gait, when compared with uninjured controls. In addition to increased loading rates and tibial shock, Milner and colleagues\textsuperscript{19} also reported increased sagittal plane knee stiffness among tibial stress fracture cases and that increased knee stiffness was associated with increased tibial shock. The same group\textsuperscript{16,17} subsequently reported that free moment, hip adduction angle, and rear foot eversion angle during gait were associated with a history of tibial stress fractures. Although these cross-sectional studies provide important insight into the biomechanical differences between tibial stress fracture cases and uninjured controls, because of the limitations of study design, it is not possible to determine whether these movement patterns were present before the injury or whether they were the result of the injury. Prospective studies are needed to determine the temporal relationship between preinjury biomechanical movement patterns and the subsequent risk of injury. Cameron and colleagues\textsuperscript{14} recently reported the findings of a large prospective cohort study that examined the association between baseline preinjury biomechanical movement patterns during a jump landing task and the subsequent incidence rate of lower extremity stress fractures during 4 years of follow-up. They reported that those that went on to develop a stress fracture during follow-up had greater internal knee rotation, greater knee valgus angle, and greater peak vertical ground reaction forces. They also reported that stress fracture cases were weaker in knee flexion and extension strength, which may have contributed to increased vertical ground reaction forces in their study and the increased sagittal plane knee stiffness and tibial shock observed by Milner and colleagues\textsuperscript{18,19} Overall, these studies suggest that patients who develop lower extremity stress fractures may exhibit specific movement patterns that place them at an increased risk for injury, and many of these movement patterns have been shown to be amenable to intervention.

Nutritional factors and body composition are also important modifiable risk factors that have been associated with lower extremity stress fracture injury. Several studies have reported that low body mass index (BMI) is an important risk factor for stress fracture injury in both men and women,\textsuperscript{3,12,14,25} and higher BMI may be a protective factor among women during basic combat training.\textsuperscript{12} Energy balance during intense physical activity may also be critical, particularly among women, in mitigating the risk for lower extremity stress fracture.\textsuperscript{15,26} Adequate levels of calcium and vitamin D are essential for bone health, and inadequate intake of these nutrients has been associated with osteoporosis and osteomalacia.\textsuperscript{15} Recent studies have also shown that inadequate levels of vitamin D and calcium may also be associated with the risk of lower extremity stress fractures.\textsuperscript{15,27–32} Increasing BMI and vitamin D and calcium intake as well as ensuring appropriate caloric intake to achieve energy balance during periods of intense physical training may be important in mitigating the risk of lower extremity stress fracture injury.

Other modifiable health risk behaviors may also be important risk factors for lower extremity stress fracture injury. Studies have shown that tobacco use and alcohol consumption may be associated with the increased risk of lower extremity stress fracture during military training.\textsuperscript{3,15} Also, the use of nonsteroidal antiinflammatory drugs, such as ibuprofen, may contribute to stress fracture risk and may also delay fracture healing.\textsuperscript{15} Finally, oral contraceptive use may be a protective factor that may reduce the risk of stress fracture among women, particularly those who are amenorrheic/oligomenorrheic.\textsuperscript{15}

**Nonmodifiable Risk Factors**

Several nonmodifiable risk factors for lower extremity stress fracture injuries have been identified, and these factors are important in identifying individuals and
populations who are at the greatest risk of injury (see Table 1). Many demographic factors have been associated with the risk of lower extremity stress fractures. Studies have consistently reported that female sex is a significant risk factor for lower extremity stress fractures and that women are as much as 5 times as likely to sustain a stress fracture during basic combat training when compared with men. Older age has also been significantly associated with the risk of lower extremity stress fractures in numerous studies conducted in military populations. Similarly, race other than black has been associated with an increased risk for lower extremity stress fracture injuries in several studies. A history of lower extremity stress fractures has been associated with an increased risk of subsequent injury. This finding highlights the importance of primary and secondary injury prevention, particularly among those with a history of prior stress fracture. Individuals with a history of stress fracture may also warrant additional screening for other modifiable risk factors before engaging in rigorous physical training. Finally, several risk factors associated with lower extremity morphology and anatomy have been examined, but most of these factors are not readily amenable to intervention.

Pathogenesis
Stress fractures have long been associated with military training programs. Many investigators have postulated the cause of stress fractures. Johnson reported on a large biopsy series in which it was postulated that an accelerated remodeling phase was likely responsible for the formation of stress fractures. However, Freidenberg proposed that stress fractures may be a nonunited fracture caused by the absence of significant callous at the fracture site. Stanitski and colleagues described abundant new subperiosteal bone formation in 2 biopsy specimens. They also note that “subthreshold mechanical insults summate beyond the stress bearing capacity of the bone” and that the onset of fracture is a combination of the stress duration and ability of bone to repair itself (Box 1).

ASSESSMENT AND DIAGNOSIS OF STRESS FRACTURE INJURIES

Clinical Evaluation
Patients will report the insidious onset of pain over a period of weeks, which typically corresponds to a particular increase in activity level or endurance training. This pain may be relieved by periods of rest and immobilization. It is important to complete a thorough medical history including diet and endocrine disorders, with an important focus on menstrual history in the female athlete. Physical examination is significant for localized tenderness to palpation when suspected injury is within a superficial bone, such as the anterior tibia. Likewise, erythema and edema may be evidence of underlying pathology. For deep structures where a stress fracture is suspected, gentle range-of-motion

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<td>Pathogenesis of stress fracture</td>
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<td>1. Increased external and muscular forces</td>
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<td>2. Resorption and remodeling</td>
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<td>3. Focal microfractures</td>
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<td>4. Endosteal and periosteal reaction, stress fracture</td>
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<td>5. Linear fracture that can advance to displaced fracture</td>
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exercises will elicit pain. Alignment and biomechanical evaluation must be examined to identify factors placing patients at an increased risk for fatigue fractures.  

**Imaging**

Plain radiographs are the initial imaging modality of choice, as they are readily available and inexpensive. Subtle signs may preclude the need for advanced imaging, such as blurring of the cortex and periosteal reaction, which may be evident. More mature stress fractures may present with a cortical lucency, frank fracture line, or evidence of new callus formation. It is important to note that radiographic signs may lag weeks behind clinical complaints. In the case of occult fracture, 3-phase bone scan with technetium 99 is very helpful, as this study has high sensitivity early in the process of stress fracture. The third phase will typically illustrate increased intensity, which sets apart boney injury from localized soft tissue injuries, such as contusion or muscle strain. Scintigraphy is not particularly specific and has been noted to have a false-positive rate nearing 50%. Magnetic resonance imaging (MRI) has been noted to be as sensitive as a bone scan but more specific. Fluid-sensitive sequences can show periosteal and marrow edema as well as localized soft tissue inflammation within 24 hours, whereas a bone scan may show increased uptake in as early as 48 hours. Cortical irregularities can be detected, and fractures will present as a characteristic linear hypointense signal.

**TREATMENT OF COMMON HIGH-RISK STRESS FRACTURES**

**Femoral Neck**

Although stress fractures of the femoral neck make up only 10% of all stress fractures, the results can lead to long-term disability as a result of pain, nonunion, and osteonecrosis of the femoral head. This injury is particularly devastating for the new military recruit who may be discharged from military service with a prolonged recovery. Talbot’s case series of 20 military recruits in the United Kingdom demonstrated a 40% medical discharge rate, and Johansson found that 60% of athletes sustaining displaced femoral neck stress fractures (FNSF) failed to return to preinjury activity levels. Patients typically present with anterior groin pain and an inability to bear weight. Tenderness to palpation is not common, but pain at the extremes of internal and external rotation will elicit discomfort.

Radiographic examination includes routine pelvis and hip views. Early in the process, radiographs are unimpressive; MRI may be warranted if symptoms fail to improve. Carey and colleagues demonstrated that military recruits who sustain FNSF have a high prevalence of radiographic findings suggestive of femoroacetabular impingement. MRI will demonstrate bony edema (most commonly to the compression side of the femoral neck), and a fracture line may be present. Fig. 1 demonstrates typical findings when investigating FNSF.

If patients present early, nonoperative treatment is often successful. If a FNSF is suspected, immediate non-weight bearing (NWB) is implemented while appropriate imaging studies can be completed. A minimum of 4 to 6 weeks of NWB is continued; as symptoms resolve, progressive weight bearing can be slowly accelerated based on symptoms and clinical examination in those patients with evidence of stress reaction on MRI. Typically patients are back to light-impact activities at 3 to 4 months. There is concern for tension-sided femoral neck fractures, as these have a higher propensity to propagate to displaced fractures. It is recommended that all tension-sided fractures as well as compression-sided fractures that comprise greater than 50% of the neck width should undergo percutaneous cannulated screw placement to prevent
displacement.\textsuperscript{47} Patients should remain NWB for 6 weeks and then progress to full weight bearing over the next 6 weeks.\textsuperscript{38} Displaced FNSF should be urgently managed with open reduction and internal fixation (ORIF) and typically takes longer for union. Evans and colleagues\textsuperscript{48} reviewed 6 cases of displaced fractures in Royal Marine recruits and noted a 100\% union rate at an average of 11 months. Fifty percent of the cases took greater than 12 months for radiographic evidence of union.\textsuperscript{48}

**Femoral Shaft**

Fatigue fractures of the femoral shaft are less common than femoral neck fractures but more common in military recruits and endurance athletes. Orava\textsuperscript{49} noted a 3\% incidence of femoral shaft stress fractures, and others have quoted rates nearing 20\% of all stress fractures.\textsuperscript{50} Niva and colleagues\textsuperscript{51} noted an 18\% incidence rate of proximal shaft fractures among 185 fatigue injuries in Finnish military recruits. Fractures of the proximal third shaft are most common. Patients will present with vague thigh pain but may also note referred hip or knee pain. There is rarely loss of hip range of motion, unlike femoral neck lesions, but similar complaints with weight bearing. The fulcrum test as described by Johnson and colleagues\textsuperscript{50} is highly correlated with stress injuries and is executed by placing the examiner’s arm beneath the midshaft of the thigh and

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**Fig. 1.** Imaging of a 26-year-old female recruit with a 4-week history of atraumatic right hip pain worsened with activity during basic training. She was made non–weight bearing for 6 weeks and completed a graded progression back to baseline activity without long-term sequelae.
providing a dorsally (posteriorly) directed force about the distal femur. A positive test is indicated by exacerbation and recreation of pain. As seen in Fig. 2, plain films are often without irregularities; but advanced imaging will demonstrate evidence of stress fracture.

Conservative treatment of femoral shaft fractures is often successful, and nonoperative treatment mirrors that for femoral neck fractures. A period of NWB is necessary and followed by progressive rehabilitation after successful evidence of radiographic healing. Weishaar and colleagues discussed the conservative management of 2 US Military Academy cadets who sustained femoral shaft stress fractures and both returned to full athletic activities at 12 weeks without complication. Displaced fractures of the femoral shaft are rare and should be treated urgently. Salminen and colleagues discussed 10 displaced femoral shaft stress fractures over a 20-year period at a national military hospital and noted an incidence of 1.5 per 100,000 person-years of military service. The investigators noted 90% had antecedent thigh or knee pain, and only one displaced fracture occurred in the proximal third shaft. These fractures were treated based on the location and fracture characteristics just as an acute fracture. Five patients underwent intramedullary nailing, 4 with dynamic compression plating and one with a condylar blade plate; the average time to union was 3.5 months.

Fig. 2. Plain films demonstrate a subtle posterior periosteal reaction. Bone scan and MRI localize the lesion, and a selected computed tomography cut illustrates incomplete posterior cortical stress fracture in an 18-year-old man with left thigh pain at the completion of basic training.
Tibia

Tibial stress fractures account for most of the lower extremity fractures and make up 50% of all reported stress fractures.\(^54\)–\(^56\) These fractures are common in both the athletic and military communities. A prospective study of US Marine Corps recruits found that tibial stress fractures made up 73% percent of the initial fatigue fracture diagnoses, and Giladi and colleagues\(^57\) noted an abnormally high incidence of 71% in Israeli Defense Force infantry recruits.\(^58\) Most tibial stress fractures occur along the posteromedial cortex in a transverse direction and result from repetitive compressive forces, notable in distance running. On the other hand, anterior tibial stress fractures pose a significant threat to the patient and are more common in repetitive jumping and leaping activities. These fractures are thought to be a result of tensile forces placed on the anterior cortex by the strong posterior musculature and have a high propensity for prolonged healing, nonunion, and completion of fracture.\(^59\) Investigators have demonstrated an incidence of 4.6% for anterior tibial stress fractures.\(^60\) Kilcoyne and colleagues\(^61\) demonstrated positive outcomes for US Naval Academy midshipmen 10 years after injury. There were no significant limitations in completing military training, and no patients were separated from the military as a result of sustaining a tibial stress fracture based on long-term follow-up.\(^61\)

On clinical presentation, most patients will complain of activity-related pain that is worse at start-up and relieves somewhat during the activity. As duration and frequency of exercise continues, pain will continue to increase. Cessation of offending activity typically improves symptoms. A minority of patients, who present with anterior tibial stress fractures, will complain of point tenderness at the site of injury and may even have observable edema. These individuals will normally maintain full range of motion of both the ankle and knee. Radiographs are normal initially but may demonstrate posteromedial periosteal reaction and callus formation in late presenting compression fractures. Rettig and colleagues\(^62\) described tension-sided stress fractures as radiographs having a wedge shaped defect in the middle third of the anterolateral tibial shaft. Bone scan and MRI may be of use if the diagnosis and clinical presentation is unclear. Fig. 3 represents a tibial stress fracture that appears benign on radiographs, but MRI demonstrates near-complete fracture of the proximal tibial diaphysis.

Compression-sided stress fractures generally respond to a period of rest and activity modification, with more severe injuries requiring a short course of immobilization. Conservative management may last 4 to 6 months before returning to sport. Anterior tibial stress fractures and posterior tibial fractures that have widening fracture lines are likely to result in delayed or nonunion and require surgical intervention. Numerous treatments have been proposed. Nonsurgical treatments of delayed unions include external electromagnetic stimulation and pulsed ultrasound. Rettig and colleagues\(^62\) demonstrated healing in 7 of 8 patients treated with pulsed electromagnetic field therapy and rest for an average of 8.7 months after initiation of treatment, and most patients were able to return to competition at 1 year. Rue and colleagues\(^63\) completed a prospective, randomized, double-blind clinical study investigating pulsed ultrasound in US Navy midshipmen and found no significant reduction in healing time. Continuing research is needed to elucidate the effectiveness of noninvasive therapies.

Surgical management is indicated for acutely displaced tibial fractures and pending or established nonunions. Green and colleagues\(^59\) treated 5 nonunions with excision and bone grafting, and all had union within 5 months. One patient was treated with excision alone and failed to unite during the follow-up period. Critics of this method note donor site morbidity when using iliac crest and the requirement of postoperative immobilization until evidence of union. Borens and colleagues\(^64\) presented promising
results with anterior tension band plating in 4 cases found in high-performance female athletes. Each fracture was grafted with demineralized bone matrix; all fractures united, with return to full activity at a mean of 10 weeks. Chang and Harris presented 5 cases of US Army servicemen who underwent reamed intramedullary nailing for chronic anterior tibial stress fractures and noted good to excellent results in all. At this time, intramedullary fixation is the preferred treatment method for chronic anterior tibial stress fractures.

**Patella**

Although a very rare fatigue injury, stress fractures of the patella require special attention because of the significant disability of extensor mechanism disruption. The patella
acts as a fulcrum to transmit force from the quadriceps to the lower leg resulting in knee extension and has been found to transmit forces of more than 200% body weight. Patellar fatigue fractures can occur in transverse or longitudinal directions and have been found after total knee arthroplasty, anterior cruciate ligament reconstruction using bone-tendon-bone autograft, and more recently after extensor mechanism repair with transosseous tunnels. They are most common in endurance athletes. Patients with patellar stress fractures will present with anterior knee pain and reduced tolerance to deep knee flexion, whereas displaced transverse fractures may present as an extensor mechanism disruption. To the authors’ knowledge, there are no reports of primary patellar stress fractures among the military population; however, Fig. 4 demonstrates increased uptake localized to the patella consistent with stress fracture.

Treatment of fatigue fractures of the patella depends on the fracture pattern. Non-displaced longitudinal or transverse fractures require a period of knee immobilization until radiographic healing is evident. Close observation and follow-up is required, as Devas described an early case of a middle-distance runner who sustained a longitudinal lateral patellar fracture treated conservatively. Three months after presentation, the patient required symptomatic fragment excision, and fibrous union was found intraoperatively. Displaced fractures require ORIF in standard fashion with Kirschner wires and tension banding or the use of cannulated compression screws.

TREATMENT OF COMMON LOW-RISK STRESS FRACTURES
Calcaneus

Fractures of the calcaneus may be the most common stress fracture of the foot and are most common among distance runners, the elderly as insufficiency fractures, and in military recruits. Among new recruits, rates of calcaneal involvement range from 0.5% to 43.0% of all stress fractures sustained during training. Greaney and colleagues found it to be the most common stress fracture of the foot in their series. Clinical presentation typically consists of heel or ankle pain worsened with

Fig. 4. Bone scan of a 25-year-old male advanced recruit with anterior knee pain after distance runs who was treated with a course of immobilization and subsequent resolution of symptoms.
activity and may have failed prior conservative treatment by primary care. Radiographs commonly show a characteristic sclerotic line superiorly in the posterior third of the calcaneus after a few weeks from the onset of symptoms (Fig. 5A). Recently, Sormaala and colleagues\textsuperscript{75} presented findings on 30 calcaneal stress fractures in Finnish military recruits and found 56% occurred in the posterior, 18% in the middle, and 26% in the anterior portions of the calcaneus. It is important to suspect calcaneal stress fractures on clinical examination. Bone scan and MRI may be quite useful, as only 15% of radiographs showed evidence of fracture (see Fig. 5B, C).\textsuperscript{75} Treatment consists of discontinuation of the offending activity with a course of NWB immobilization. Most patients will return to activities after months of light duty, and some military careers may be cut short. Although calcaneus fractures are common, complete and displaced calcaneal stress fractures are rare.

\textbf{Tarsal Navicular}

Stress fractures of the tarsal navicular bone are uncommon injuries, and most are seen in elite athletes and dancers participating in sports requiring sprinting and abrupt changes in direction. Reported rates in the military have historically ranged from 1% to 3\%.\textsuperscript{57,58,76–78} Patients will present with activity-related pain to the dorsal aspect of the midfoot, and delayed diagnosis is not uncommon. Maneuvers such as resisted plantar-flexion and jumping on the affected limb will often exacerbate pain.

\textbf{Fig. 5.} Radiograph demonstrates a common pattern of calcaneal stress fracture with increased opacity to the posterosuperior margin of the calcaneus. Bone scan and MRI show a different stress fracture located at the inferior aspect of the calcaneal tuberosity.
Radiographs may be inconclusive initially and necessitate the use of advanced imaging. Stress fractures of the tarsal navicular commonly occur in the central one-third and are oriented in the sagittal plane (Fig. 6).

Treatment of navicular stress fractures remains in favor of nonoperative treatment with a 6-week period of NWB and immobilization. Khan and colleagues\textsuperscript{79} reported on 86 clinical stress fractures, and 86% of patients treated with NWB cast immobilization returned to sport compared with 26% who continued weight bearing and limited activity. Fifteen patients in the latter group required at least one operation. Some investigators propose that ORIF with or without bone grafting may return the athlete faster, but Saxena and Fullem\textsuperscript{80} demonstrated no significant difference between surgical and conservative measures. ORIF with bone grafting has shown favorable results in both primary and delayed union groups.\textsuperscript{79–82} A 2010 meta-analysis by Torg and colleagues\textsuperscript{83} found that there was no significant difference in outcomes for NWB cast immobilization and surgery. Thus, the investigators concluded that conservative treatment should remain the standard of care.

**Metatarsals**

Fractures of the metatarsals have long been associated with military service and marching when Briethaupt\textsuperscript{84} described Prussian soldiers with swollen and painful feet after completing long marches. It has subsequently been described as “march foot.”\textsuperscript{84,85} The second metatarsal neck is the most common location for stress fractures; the third and fourth metatarsals may be involved; the proximal fifth metatarsal stress fracture is less common. Fig. 7 demonstrates early and late radiographic findings of a third metatarsal fracture. Stress injury to the first metatarsal is uncommon.

![Figure 6](image)

**Fig. 6.** A 20-year-old female recruit who presented with a 6-week history of mild midfoot pain noted only during endurance runs. Sclerosis to the medial distal aspect is noted on plain films, and bone scan and MRI confirm diagnosis of stress fracture.
and thought to be protected by its relative mobility. The relative immobility of the second metatarsal may place this ray prone to injury. Donahue and Sharkey have shown that the mean peak strain in the second metatarsal is twice that experienced by the fifth metatarsal and simulated muscle fatigue significantly increases this strain as does plantar fasciotomy. Soldiers and athletes will typically complain of forefoot pain and may likely be able to localize the pain to a given metatarsal. Referral to an orthopedic provider typically occurs after a trial of conservative management by the primary care team. Treatment of the second to fourth metatarsal (MT) injuries consists of 4 weeks of immobilization in a short-leg NWB cast, a walking cast, or walking boot tailored to each patient’s needs.

Special consideration is paid to the fifth metatarsal stress fractures. These injuries are common within jumping sports and have a tendency for delayed union or nonunion requiring operative intervention. Patients will complain of lateral foot pain worse with running and jumping, and prodromal symptoms should provide a clue to the diagnosis. Radiographs may show a cortical lucency to the plantar aspect of the fifth metatarsal just distal to the tuberosity and incomplete callus. In cases of delayed presentation or completion of stress fracture, the medullary canal may be obliterated by sclerotic bone. Fig. 8 demonstrates the progression from prodromal complaint to acute fracture and finally to healed stress fracture. Treatment depends on the stage at presentation, and those with short duration and no radiographic evidence of fracture can be treated conservatively with metatarsal bracing and limited weight bearing. Six weeks of cast immobilization or operative fixation is an acceptable treatment of patients with prolonged pain or radiographic evidence of fracture. Intra-medullary fixation is normally achieved with screw fixation, which is countersunk to
reduce soft tissue irritation. Delayed unions and those showing intramedullary sclerosis may require curettage. DeLee and colleagues\textsuperscript{89} reported excellent results in 10 athletes in which intramedullary fixation was used to treat diaphyseal stress fractures and found that all fractures united, and the athletes returned to sport on an average of 8.5 weeks.\textsuperscript{89}

Miscellaneous Stress Fractures

Other recognized sites of stress fractures in the lower extremity include the medial malleolus, talus, and great toe sesamoids. Upper extremity stress fractures are very rare and can occur in individuals completing repetitive lifting tasks, such as weightlifting and rifle drill training.\textsuperscript{90,91} Honor guards are popular in the military, and some groups may practice for multiple hours per day reaching rates of 100 rotations per minute using the rifle. Stress fractures of the ulna have been noted in this unique population at a higher incidence than the general population.\textsuperscript{92} Stress fractures of the medial malleolus and talus can occur with repetitive ankle dorsiflexion caused by impingement and are rare injuries. Fractures typically occur at the intersection of the tibial plafond and malleolus, exiting vertically or obliquely.\textsuperscript{93} The lateral process of the talus is also prone to injury with forceful supination of the foot.\textsuperscript{38} Imaging including plain films, bone scan, and MRI may be used. These fractures tend to respond to NWB cast immobilization, whereas return to activity can be accelerated with ORIF\textsuperscript{94} of medial malleolar fractures. Both operative and conservative management have good outcomes and return-to-sport rates. Sesamoid fractures of the great toe occur from repetitive dorsiflexion exercises of the first ray (Fig. 9). These injuries respond to NWB cast immobilization. Symptomatic fibrous unions can occur and may be treated with excision.\textsuperscript{95}

THE PREVENTION OF LOWER EXTREMITY STRESS FRACTURES

Although several promising modifiable and potentially modifiable risk factors for lower extremity stress fracture injuries have been identified and several interventions targeting these risk factors have been proposed, few have been adequately evaluated in the...
The purpose of this section is to provide an overview of the existing evidence supporting primary and secondary injury prevention interventions for lower extremity stress fracture injuries.

**Primary Injury Prevention**

In a systematic review, Jones and colleagues summarized 9 studies that evaluated the efficacy of primary injury prevention interventions in reducing the incidence of lower extremity stress fracture injuries in military populations. The studies examined interventions that consisted of modifications to the physical training program or the footwear used by Army and Marine Corps recruits during basic combat training. Few of the studies examined reported statistically or clinically significant reductions in lower extremity stress fractures and those that did typically had low overall-quality scores. More recently, studies have demonstrated that limiting running distance and overall training volume may significantly reduce but not eliminate the risk of lower extremity stress fractures in military training populations, particularly as more sedentary and less physically fit individuals enter military service.

As noted previously, lower extremity biomechanical movement patterns that place individuals at an increased risk for lower extremity stress fractures may be important targets for injury prevention interventions. Recent studies have demonstrated that movement retraining interventions might be effective in mitigating these factors and potentially the subsequent risk for lower extremity stress fractures. Crowell and Davis reported that a 2-week (8 sessions) gait retraining intervention resulted in significant reductions in peak positive acceleration of the tibia, vertical force impact peak, and average and instantaneous vertical force loading rates immediately following the intervention and at the time of a 1-month postintervention assessment. Decreases in tibial acceleration (50%) and reductions in vertical force loading rate (30%) and vertical force impact peak (20%) seemed to be clinically significant; however, whether these changes are permanent or whether they actually result in reduced incidence rates of lower extremity stress fractures remain unclear. Regardless, these data suggest that movement retraining interventions that target high-risk biomechanical movement patterns may play an important role in the primary prevention of lower extremity stress fractures.
Dietary interventions focused on maintaining energy balance during rigorous physical activity and ensuring that adequate calcium and vitamin D are consumed may also be important primary prevention interventions for lower extremity stress fractures. A recent large randomized controlled trial examining the effectiveness of calcium and vitamin D supplementation in reducing the risk of stress fractures in female Navy recruits reported a statistically significant 20% reduction in those that received the intervention compared with the control (placebo) group.27 The investigators noted that this relatively low-cost, low-risk intervention could significantly reduce morbidity and financial costs associated with lower extremity stress fractures in female recruits. Whether or not vitamin D supplementation in the absence of calcium supplementation or supplementation in men is an effective intervention to reduce the incidence of stress fractures remains unclear. A recent review and meta-analysis suggest that vitamin D supplementation may only be effective in preventing stress fractures when it is administered in combination with calcium supplements.96,97

Improving preaccession physical fitness levels and engaging in moderate-intensity weight-bearing physical activities that include jumping and resistance exercises several times a week can increase bone mineral density and may offer a preventive effect, particularly in high-risk recruits. Research suggests that mechanical loading, in appropriate volume and intensity, can improve bone qualities and injury resilience98; however, studies have yet to systematically evaluate the effectiveness of a carefully developed and monitored exercise program in reducing the risk of lower extremity stress fracture injuries in military recruits.15 As a result, this should be an important target for future injury prevention research.

**Secondary Injury Prevention**

Because individuals with a history of lower extremity stress fractures are much more likely to sustain a subsequent stress fracture in the future, these individuals should be identified for additional injury screening before accession. A careful evaluation of the modifiable and other nonmodifiable risk factors associated with lower extremity stress fractures is warranted in these individuals. In particular, additional screening should focus on women with a low BMI and those that may have a history of menstrual irregularity. Screening for serum vitamin D concentrations (eg, 25-(OH)-D) might also be warranted in individuals with a history of a prior stress fracture before engaging in a rigorous physical activity program. Individuals with low serum vitamin D concentrations might benefit from dietary interventions or supplementation, and women with menstrual irregularities might benefit from low-dose oral contraceptives to reduce their risk for lower extremity stress fractures during initial entry-level military training.15 Individuals with a history of lower extremity stress fractures might also benefit from additional biomechanical movement screening to identify high-risk movement patterns that may be addressed through movement training interventions as noted earlier. Regardless, individuals with a history of lower extremity stress fractures should garner additional scrutiny before engaging in a rigorous weight-bearing physical training program.

**SUMMARY**

Stress fractures of the lower extremities are common among the military population and, more specifically, military recruits who partake in basic training. Both intrinsic and extrinsic factors play a role in the development of these injuries, and it is important to identify those individuals at risk early in their military careers. Some of these factors are modifiable, so they may become preventable injuries. It is important to reiterate that one stress fracture places the soldier at risk for future stress fractures; but the first injury
should not be reason enough for separation from the military, as literature would support no long-term deficits from properly treated stress fractures. Early in the process, radiographic analysis is typically normal; continued pain may warrant advanced imaging, such as scintigraphy or MRI. Most stress fractures that are caught early are amendable to nonoperative management consisting of a period of immobilization and NWB followed by progressive rehabilitation to preinjury levels. Complete or displaced fractures may require operative intervention as do tension-sided FNSF. Improving dietary and preaccession physical fitness levels may play a role in reducing the incidence of stress fractures in the active-duty military population. It is important to keep in mind when evaluating soldiers and athletes who present with activity-related pain that stress fractures are not uncommon and should be given significant consideration.

REFERENCES


Stress Fractures in the Military