ABSTRACT

Stress fractures are part of a continuum of changes in healthy bones in response to repeated mechanical deformation from physical activity. If the activity produces excessive repetitive stress, osteoclastic processes in the bone may proceed at a faster pace than osteoblastic processes, thus weakening the bone and augmenting susceptibility to stress fractures. Overall stress fracture incidence is about three cases per 1,000 in active duty Servicemembers, but it is much higher among Army basic trainees: 19 per 1,000 for men and 80 per 1,000 for women. Well-documented risk factors include female sex, white ethnicity, older age, taller stature, lower aerobic fitness, prior physical inactivity, greater amounts of current physical training, thinner bones, cigarette smoking, and inadequate intake of vitamin D and/or calcium. Individuals with stress fractures present with focal tenderness and local pain that is aggravated by physical activity and reduced by rest. A sudden increase in the volume of physical activity along with other risk factors is often reported. Simple clinical tests can assist in diagnosis, but more definitive imaging tests will eventually need to be conducted if a stress fracture is suspected. Plain radiographs are recommended as the initial imaging test, but magnetic resonance imaging has higher sensitivity and is more likely to detect the injury sooner. Treatment involves first determining if the stress fracture is of higher or lower risk; these are distinguished by anatomical location and whether the bone is loaded in tension (high risk) or compression (lower risk). Lower-risk stress fractures can be initially treated by reducing loading on the injured bone through a reduction in activity or by substituting other activities. Higher-risk stress fractures should be referred to an orthopedist. Investigated prevention strategies include modifications to physical training programs, use of shock absorbing insoles, vitamin D and calcium supplementation, modifications of military equipment, and leadership education with injury surveillance.

KEYWORDS: stress fracture; risk factors; diagnosis; treatment

Introduction

Stress fractures are part of a continuum of changes in the bone in response to mechanical stress. The continuum spans events from normal bone remodeling to a frank fracture. Figure 1 is a summary of terms used to describe this spectrum, obtained from a review of various terms used in the literature and clinical experience. The term “stress reactions” has been used to identify conditions where early changes occur in the bone and the Soldier experiences pain symptoms, but there is no evidence of bone lesions on imaging. Stress fractures usually refer to conditions where there are distinct partial or incomplete fracture lines on imaging. The term “bone stress injury” has been used to refer to the portion of the continuum (Figure 1) encompassing both stress reactions and stress fractures.

Figure 1  Spectrum of bone changes in response to repetitive stress.

Bone stress injuries are typically associated with habitual mechanical deformation of the bone. The injury generally occurs in individuals with otherwise healthy bones, often in association with unaccustomed but repetitive physical activity. This type of fracture is often referred to as a “fatigue fracture” and is to be distinguished from “insufficiency fractures,” which are partial or incomplete bone ruptures due to loading on bone
that has become osteopenic with aging or disease (e.g., hypervitaminosis A, sarcoma). Insufficiency fractures may occur spontaneously in association with normal loading or minimal trauma that would not result in a fracture in healthy bones.9–14

Soldiers involved in heavy physical activity may be at risk for stress fractures, especially if the activity involves sudden increase in frequency, duration, or intensity. Recovery times can be extended, negatively affecting both Soldier and unit effectiveness for a considerable time.15–18

This article covers the etiology, epidemiology, diagnosis, treatment, and prevention of fatigue fractures, which will hereafter be referred to as stress fractures.

Etiology

Bone will bend when subjected to impact forces induced by activities like running or foot marching with loads. They will return to their original configuration when the impact forces are reduced or removed. The repetitive bending results in an increase in cyclic hydrostatic pressures that are sensed by osteocytes within the bone matrix. Mechanical pressures stimulate osteocyte-directed transcription of osteoclasts, which begin the bone remodeling process. If the repetitive mechanical stress is applied gradually over time (i.e., progressive overload), normal bone remodeling occurs. That is, osteoclastic processes, which resorb bone, approximately balance osteoblastic processes, which form new bone. However, if the repetitive stress is applied in a relatively short time, as with a long foot march with a heavy load for which the Soldier has not sufficiently trained, osteoclastic processes may proceed at a faster pace than osteoblastic processes. This imbalance produces a vulnerable period when the bone is weakened and susceptible to rupture.5,19,20

Stress fractures appear more likely to occur where bone remodeling is slower. Areas of slow remodeling include compact (cortical) bone, the long bone diaphysis (Figure 2), and bodies of cuboid-shaped bones like the vertebrae, tarsals, and carpals. In spongy (cancellous) bone where more active remodeling occurs, there is a lower likelihood of stress fractures. Cancellous bone is contained in the metaphysis and epiphysis of both long and square bones (Figure 2). Cancellous bone has a metabolic turnover rate eight times faster than cortical bone.5,6,12,21

Epidemiology

Incidence

Stress fractures are a commonly encountered injury in athletics, among military recruits22–29 and among trained military personnel.29–32 A study that examined the entire population of US Army basic trainees from 1997 to 2007 reported incidences of 19 cases per 1,000 Service members (SMs) for men and 80 cases per 1,000 SMs for women.28 The incidence among active duty military personnel from 2003 to 2012 was 2.7 cases per 1,000 SMs.20 During the Central Burma campaign in the Second World War, 80 stress fracture cases were reported in one 7,000-man infantry unit (1.1% incidence) during a long road march.33,34 Early in the study of this injury, stress fractures were termed “march fracture” because Soldiers would often present with this injury after road marching14–18; however, cases emerged in which the onset was insidious and the injury could not be linked to a single event.35,37,39 Breithaupt is credited with the first description of the condition in Prussian Army Soldiers.37 During the Second World War, cases and case series began to appear in the literature in both British33 36–38,40 and American33 36–38,40 military training.

We obtained data on ambulatory (outpatient) stress fractures directly from the Defense Medical Epidemiology Database (http://www.health.mil/Military-Health-Topics /Health-Readiness/Armed-Forces-Health-Surveillance-Branch/Data-Management-and-Technical-Support/ Defense-Medical-Epidemiology-Database) for the Army, Navy, Marine Corps, and Air Force. The data were visits to medical care providers with International Classification of Diseases, Ninth Revision codes of 733.93 to 733.98 (the codes for stress fractures at various anatomical locations), diagnosed from 2006 through 2014. The overall rate was 17.3 visits per 1,000 SMs. Data by year, sex, age, and military service are shown in Figure 3. Rates tended to decrease in the period examined (Figure 3A). Military Servicewomen had 3.6 times the stress fracture rate of military Servicemen (Figure 3B) and rates decreased with age (Figure 3C). The Marine Corps and Army had the highest rates and the Navy had the lowest (Figure 3D).
The reason for the decrease over years is not clear, but there have been considerable efforts to reduce the incidence of stress fractures and other injuries at many basic training sites. The higher rate in younger SMs may be due to the larger number of military recruits in these younger groups: one study of military stress fractures showed that most of these occurred in military recruits, with an incidence of 40 cases per 1,000 recruits, compared with three cases per 1,000 active duty SMs. Also, older SMs tend to be in administrative and/or supervisory positions and may perform less heavy physical activity.

**Risk Factors**

Considerable research has been conducted to identify factors that increase stress fracture risk. Well-documented risk factors include female sex, older age, lower aerobic fitness, prior physical inactivity, greater amounts of current physical training, thinner bones, cigarette smoking, inadequate intake of vitamin D and/or calcium, and limited support include high foot arches, older running shoes, genu varus, irregular menses, limb-length discrepancies, and particular movement patterns.

The sex difference in stress fracture risk may be related to fitness levels, bone characteristics, and/or anatomy. Women have lower average fitness levels than men and lower fitness is associated with higher overall injury rates as well as a higher incidence of stress fractures. In the bones of the lower body, where most stress fractures occur, women have a lower bone section modulus and a lower bone strength index (ratio of section modulus to bone length) than men. Female bones are thinner and narrower, which provides less bone strength. With regard to anatomical differences, women have wider pelvises, which result in a varus tilt of the hip and a larger bicondylar angle, which places greater stresses on the hips and lateral aspects of the knee and lower leg during physical activity. Both men and women with wider pelvises have higher stress fracture incidence, suggesting that a wider pelvis alone (regardless of sex) increases injury risk.

The association between age and stress fractures may be related to changes in bone with aging. Bone mass declines with age, primarily in the spongy bone compartments. Losses in spongy mass in the distal tibia amounted to 0.24% per year and 0.40% per year for men and women, respectively, in one study. This loss may be due to a reduction in the number of osteoblastic stem cells or a reduction in the lifespan of the osteoblasts themselves. The overall loss of bone mass with age would affect bone strength, and age-related effects on osteoblasts would result in slower bone remodeling, thus increasing susceptibility to activity-induced stress fractures. However, as mentioned, most stress fractures manifest in the cortical (compact) bone. In this compartment, there are age-related changes in the mechanical properties of the collagen network (upon which bone minerals deposit), which reduce strength, modulus, and ability to absorb energy, while increases in bone porosity reduces bone stiffness and strength. These changes likely contribute to the higher age-related stress fracture risk.

There is higher stress fracture risk among those of white ethnicity and lower risk among those of black ethnicity. This could be partly related to the higher bone mineral density (BMD) in blacks compared with other racial/ethnic groups. This difference persists after adjustments for body composition, dietary history, sun exposure, biochemical bone markers, lifestyle characteristics, and other factors. In addition to higher BMD, studies of the female femur have shown that there are differences in bone geometric properties between black women and white women: black women have longer and narrower femora with thicker cortical areas and smaller medullary areas. These factors increase mechanical strength by contributing to lower bending stresses in the cortical areas during physical activity. The higher BMD and the manner in which the bone architecture is arranged may contribute to the lower stress fracture incidence in blacks.

The length of long bones in the lower body (i.e., femur, tibia, fibula) is highly related to height, with correlations in the range of 0.9. Taller individuals with presumably longer bones may experience more bending
and strain on their lower-body long bones during physical activity. One study showed that men with stress fractures had longer femora compared with those without stress fractures, and the longer bones contributed to lower bone strength.

Prior physical activity may reduce stress fracture risk during current activity, because of changes in bone tissue induced by the prior activity. Physical activity, especially activities involving high impact forces (e.g., running, soccer, basketball, gymnastics) increase bone mineral content, BMD, bone size, bone mass, and result in activity-specific bone remodeling. Effects of physical activity may be larger in men than in women and the maintenance of physical activity appears to be important for the maintenance of bone mass.

**Clinical Evaluation and Diagnosis**

Individuals with stress fractures present with localized pain that is aggravated by physical activity and reduced by rest. Focal tenderness is present in most cases; swelling and erythema may be present. Patient history notes a recent increase in the frequency, duration, or intensity of physical activity. Simple clinical tests may be useful in the initial diagnosis, but more definitive imaging tests will eventually need to be conducted if stress fractures are suspected. The potential risk factors noted in the previous section should be considered in the overall evaluation.

Simple clinical tests include the tuning fork test, patellar-pubic percussion test, hop test, and the fulcrum test; however, only the two former tests have been evaluated for their ability to detecting stress fractures. For the tuning fork test, the Soldier is supine and a vibrating 128hz tuning fork is applied to and moved along the boney surface. Pain during tuning fork application is considered a positive sign. At least three studies have compared the tuning fork test (i.e., pain exacerbation on application of the tuning fork) to bone scans (primarily tibia and fibula but also foot bones) and found sensitivities (i.e., ability to correctly identify a stress fracture) ranging from 71% to 80% and specificities (i.e., ability to detect those without stress fractures) ranging from 60% to 67%. The patellar-pubic percussion test was developed to assess hip fractures. With the Soldier supine, the evaluator listens with a stethoscope at the pubic symphysis of the affected side while tapping on one patella and then the other. Similar sounds indicate a lower likelihood of a fracture, but if the bone is disrupted, the sound on one side will be diminished in pitch and loudness compared to the other side. Two studies examining the accuracy of this test for detection of hip fractures found sensitivities of 79% and 96% and specificities of 86% and 95%.

Other clinical tests that have not been specifically evaluated for sensitivity but are often used in suspected stress fracture cases include the hop and fulcrum tests. For the hop test, the individual hops on the affected leg and localized pain is assumed to indicate a positive test. The fulcrum test is used for suspected femoral stress fractures. The patient is seated on the examination table with lower legs dangling off the table. The evaluator places one of his arms under the affected thigh and with the other hand pushes down on the distal femur. Increasing pressure on distal femur produces increasing discomfort, pain, and apprehension. The unaffected leg serves as a control.

Although useful for an initial evaluation, clinical examinations are generally not sufficient for the diagnosis of stress fractures because the results of tests can vary depending on the stage of the injury on the pathological spectrum (Figure 1). Imaging studies should be conducted when clinical evaluation provides suspicion of a stress fracture. Imaging tests include plain radiographs, bone scans, and magnetic resonance imaging (MRI). Plain radiographs have a high initial incidence of false-negative results because the injury is generally not evident on radiographs until 2 to 4 weeks after the onset of pain. Bone scans can produce many false-positive results. Despite the cost, MRI may be the most useful test because it may detect stress fracture-related abnormalities within 1 to 2 days of the injury. A systematic review of high-quality studies evaluating MRI found sensitivities of 68% to 99% and specificities of 92% to 84%. With MRI, the low rate of false-negative results may reduce the need for additional testing. Nonetheless, plain radiographs are a low-cost option and are recommended as an initial imaging test by the American College of Radiology. In the case of Soldiers who must perform high-risk physical activity that may exacerbate symptoms or the stress fracture itself, a negative finding on plain radiography should be confirmed with MRI.

In a setting with limited diagnostic ability (e.g., deployment in isolated areas), a presumptive diagnosis can be provided without radiographic imaging when multiple risk factors and findings on physical examination for stress fractures are present. However, imaging is always recommended for high-risk stress fractures or if the patient’s symptoms do not improve. Referral to higher levels of medical care should be considered in these cases.

**Treatment**

It is important to distinguish between stress fractures that are at high risk for nonunion versus those that will heal with a lower risk of complications. Clinical experience suggests that stress fractures can be stratified into
A number of interventions have been tested to reduce the incidence of stress fractures. These include modifications to physical training programs, use of shock-absorbing insoles, vitamin D and calcium supplementation, modifications of equipment, and leadership education with injury surveillance.

Modification of Physical Training Programs

It should not be surprising that many successful interventions to reduce the incidence of stress fractures in the military have focused on modifications of group physical training programs. These modifications have involved reducing the frequency or duration of certain physical activities or alternating exercised muscle groups in different exercise sessions so that previously exercised muscle groups are provided rest and recovery (e.g., upper body versus lower body). The current Army physical training doctrine called Physical Readiness Training was specifically designed to reduce injuries through a reduction in excessive running mileage, increase in exercise variety (cross-training), and gradual progressive overload. It was shown to reduce stress fracture incidence after implementation. Other studies have also shown that reducing excessive running and/or marching...
mileage during training reduced stress fractures while resulting in similar improvements in aerobic fitness when compared with longer running or marching mileage.124–126 One study involved multiple modifications to the physical activities during female Australian recruit training. Reducing marching speed, allowing trainees to march at their own step length (rather than marching in step), running and marching in more widely spaced formations, running on grass, and reducing running mileage was successful in reducing pelvic stress fractures in women.127

**Shock-Absorbing Insoles**

At least six studies have investigated whether shock-absorbing insoles can prevent stress fractures.50,128–132 However, evaluation of these investigations is complicated by differences in types of materials used (e.g., urethane, neoprene, viscoelastic polymer), shape of the insole (i.e., custom molded versus generic off-the-shelf), the length of the material (i.e., heel cup versus full length), and method of stress fracture diagnosis (e.g., radiograph, bone scan). Despite these factors, when the results of five studies50,128–131 were pooled in a meta-analysis, there was an overall reduction in stress fracture incidence.133 The protective effect was greater for femoral and tibial stress fractures and less so for metatarsal stress fractures. The results of the meta-analysis (pooled results)133 are shown in the second column of Table 2. Note that in Table 2, an odds ratio <1 indicates the “protective” effect and that insole group had a lower stress fracture risk.

Since this meta-analysis133 was completed, one additional study was published that examined the effectiveness of a cellular polyurethane foam insole for the prevention of stress fractures during British Royal Marine training.132 We added that study to the meta-analysis conducted previously,133 using the random model in Comprehensive Meta-Analysis Statistical Package (version 3). Results are shown in the third column of Table 2. Because of the many individuals tested in the new study,132 the confidence interval around the estimated effects sizes were considerably narrowed. Adding this study to the previous five provided more support for the contention that shock-absorbing insoles appear to reduce the incidence of stress fractures, especially in the femur and tibia.

**Vitamin D and Calcium Supplementation**

Vitamin D is important for bone health because it increases calcium absorption from the gastrointestinal track and controls calcium deposition in the bone.134 The current recommended daily allowance of vitamin D is 600IU (15µg/d).131 25-hydroxyvitamin D [25(OH)D] is the accepted clinical indicator of vitamin D status and includes contributions from both cutaneous (solar) and dietary sources. Several studies indicated that low levels of circulating 25(OH)D or low dietary intake of vitamin D were associated with a higher risk of stress fractures in military SMs.68,69,136,137

A meta-analysis of eight placebo-controlled studies involving elderly women suggested that supplementation with vitamin D (with or without calcium) reduced the incidence of nonvertebral fractures and hip fractures.138 One study139 administered a dietary assessment at the start of a study and followed female runners for stress fractures for about 2 years. Investigators found that each additional cup of skim milk consumed at baseline was associated with a 62% reduction in stress fracture incidence. There was a dose-response relationship such that higher baseline calcium consumption was associated with a lower rate of subsequent stress fractures (secondary data analysis140). There was also a nonsignificant tendency for higher vitamin D intake to reduce stress fracture incidence.

The only double-blind, placebo-controlled study141 examining the influence of vitamin D and calcium consumption on stress fractures was conducted among US female Navy recruits. One group was daily supplemented with 800IU of vitamin D and 2,000mg of calcium, while a second group received a placebo. At the end of the 8 weeks of training, the supplemented group had a 20% lower stress fracture incidence compared with the placebo group. Another study142 was conducted among male South African recruits who either did (n = 247) or did not (n = 1,151) receive a 500mg/d calcium supplement. Over 9 weeks of training, the supplemented recruits had a 0.4% incidence of stress fracture, whereas the nonsupplemented recruits had a 1.2% incidence. However, because of the relatively small number of stress fractures (n = 15), the difference was not statistically significant (p = .26, secondary data analysis). Overall, there does appear to be some evidence that higher levels of calcium and/or vitamin D intake may reduce stress fracture incidence in military training, but further research is certainly needed, especially in men.

**Table 2 Meta-Analysis Showing Pooled Results of Studies Examining the Effects of Insoles on Stress Fractures**

<table>
<thead>
<tr>
<th>Insole/No Insole Combined Meta-Analysis,132,133 OR (95% CI)</th>
<th>Insole/No Insole OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any stress fracture</td>
<td>0.44 (0.25–0.78)</td>
</tr>
<tr>
<td>Femoral stress fractures</td>
<td>0.42 (0.24–0.75)</td>
</tr>
<tr>
<td>Tibial stress fractures</td>
<td>0.51 (0.32–0.82)</td>
</tr>
<tr>
<td>Metatarsal stress fractures</td>
<td>0.29 (0.08–1.05)</td>
</tr>
</tbody>
</table>

CI, confidence interval; OR, odds ratio.
Modification of Military Equipment

At least one investigation\(^\text{142}\) has suggested that when men and women carry identical loads over identical distances, women report considerable problems with load-carrying equipment. Especially prevalent were problems with shoulder straps of the rucksack, fit of pistol belts, and fit and stability of the rucksack.\(^\text{142}\) One study modified the equipment of female Israeli border soldiers by using a shorter rifle; lighter, better-fitting combat vest; and reducing the total load carried by 25%. After the interventions were introduced, there was a 56% reduction in stress fracture incidence.\(^\text{143}\) Another study modified the combat vest by approximating it to the female center of gravity and providing a more comfortable upper body fit. However, this did not significantly affect stress fracture incidence in these soldiers.\(^\text{144}\)

Leadership Education, Enforcement, and Surveillance

Leadership education, enforcement of injury prevention guidelines, and systematic surveillance were found to reduce femoral neck stress fractures (FNSFs) by 58% among men and 50% among women.\(^\text{41}\) Leadership education involved an injury prevention curriculum during a precommand course. Enforcement of injury prevention guidelines was enhanced by the full-time assignment of a physical therapist to training brigades to oversee training and provide consultation on injury prevention measures. Surveillance involved systematic recording of FNSF at the hospital and reporting the incidence to commanders. Command reports included (1) near–real-time notification to commanders of FNSF in their units, (2) quarterly graphs to battalion commanders showing FNSF incidence by sex with comparisons to the previous quarter and the same quarter in the past 2 years, and (3) annual reports to brigade commanders providing reports for each battalion by company.

Conclusion

Stress fractures are serious injuries that can result in long rehabilitation and recovery times. Stress fractures should be considered in the clinic when there is pain on activity that is relieved with rest, focal tenderness, and patient history with a recent increase in the frequency, duration, or intensity of physical activity. Simple clinical tests include the tuning-fork test (primarily for tibia and fibula) and the patellar-pubic test (for hip fractures) among others. Eventually, suspected stress fractures will require imaging studies and MRI provides a more definitive diagnosis and earlier detection compared with other methods. Prevention is the primary goal and research suggests that this can be achieved by avoiding sudden increases in the volume of physical activity, adequate vitamin D and calcium intake, use of shock-absorbing insoles, and other strategies.

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Disclosure

The authors have nothing to disclose.

References


Stress Fractures


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Dedicated to the Indomitable Spirit and Sacrifices of the SOF Medic