There are more than 16 million runners in the United States who train a minimum 100 days per year. Runners can be separated into the following three categories on the basis of training frequency: (a) core participants (>50 runs/yr), (b) frequent runners (>100 runs/yr), and (c) core runners (>224 runs/yr). The core runner category includes most competitive high school and collegiate runners in the United States as well as recreational runners training for distances ranging from 5 km to half-marathons (13.1 miles). In addition to the high running frequency per year, the core runner averages 31 miles per week.

Given the repeated stresses and high impact loads of running, up to 46% of runners suffer a running-related injury each year. Further, lower extremity stress fractures (LESFs) are reported to account for up to 20% of all injuries in athletes, with runners and track athletes experiencing the greatest incidence. Among runners, the tibia is highly susceptible to fracture, accounting for up to 55% of all LESFs. Combining the high incidence of LESFs in runners with recovery typically requiring up to 8 weeks, participation in training and competition can be greatly disrupted.

In addition to the pain and disability a runner experiences as a result of an LESF, a high rate of injury reoccurrence (36%) has been documented. Because runners repeatedly experience impact forces that are two to three times body weight with each step, load absorption, and fatigue influence LESF injury risk. Given the incidence and recurrence rate, understanding of training strategies that can minimize the risk of LESF is important. Thus, the purposes of this report are to (a) discuss risk factors for LESF in runners and (b) describe preventive interventions to minimize LESF injury risk. Because training volume and intensity differs among runner groups, this report will focus on the core runner (>20 mi/wk).

### Risk Factors for LESF

The two major classifications of stress fractures described in the literature are fatigue fractures and insufficiency fractures. Fatigue fractures are primarily caused by overstress, which primarily affect cortical bone, whereas insufficiency fractures are primarily caused by low bone mineral density. Either type of stress fracture occurs as a result of the inability of the bone to adequately adapt to the stress imposed upon it.
**Bone Adaptation to Stress**

According to Wolff’s Law, bone tissue adapts to the specific demands that are imposed. In response to stress loading, micro-damage occurs within the structure of the bone. In response, osteoclast cell activity predominates (i.e., removal of mineralized bone matrix). With adequate recovery time, the micro-damage is repaired through increased osteoblast cell activity (i.e., new bone formation). As long as the stress loading remains within the limits of adaptation and recovery, increased bone strength will result. When a normal balance between osteoclast and osteoblast cell activity is disrupted, however, a pathologic condition can develop. Excessive running volume and inadequate recovery time can lead to bone weakness and development of a LESF. A stress fracture is most likely to occur during an early phase of training (i.e., first 40 days) or when a training regimen is substantially altered.

**Impact Forces**

An important distinction should be recognized between internal and external loading. Internal loading is produced by muscles, tendons, and ligaments, whereas external loading results from ground reaction forces (GRF) that are generated by impact of the foot against the ground. GRFs measured during running provide an approximation of the magnitude of internal load imposed on the body tissues. Because determination of the stress imposed on the tibia during running is difficult to measure, GRFs provide as an acceptable surrogate for representation of the load.

Although GRFs act in all three planes, the vertical component is most commonly examined. Vertical GRF typically has two peaks in heel-striking runners and one peak in forefoot-striking runners (Figure 1). The initial peak is the smaller of the two peaks in heel-strikers and is absent in forefoot-strikers. The magnitude of the peak vertical GRF is an important indicator of internal tissue loading. The loading rate is represented by the slope of the initial GRF (i.e., from foot strike to initial peak). A recent systematic review provided evidence that both the average and instantaneous vertical loading rates are greater in individuals who have sustained LESFs compared to those who have not. However, the magnitude of peak vertical GRF does not substantially differ between the two groups. Thus, an elevated loading rate appears to be an important risk factor for LESF.

**Fatigue**

Fatigue may play an important role in the development of an LESF. At the end of a fatiguing run, GRFs have been observed to be greater in runners with a history of stress fracture than runners without such a history. Researchers examining the role of muscle fatigue on bone strain in a canine animal model reported a decrease in the ability of the musculature to dissipate GRFs and a 36% increase in tibial strain. The reduced capability of the musculature to dissipate force when fatigued results in greater load on the tibia. Muscle fatigue also alters running biomechanics, which has been associated with a 25% increase in vertical GRF. Researchers have suggested that runners tend to compensate for elevated vertical GRF by increasing heel strike at initial ground contact. Consequently, efforts to prevent LESF should focus on (a) alteration of training regimens to reduce impact loading of the lower leg and (b) development of muscle fatigue resistance in the lower extremity.

**Preventive Interventions**

**Resistance Training**

Female runners with a history of LESF have smaller calf girth and lesser lower leg muscle mass than do other...