GREETINGS FASIG MEMBERS!

How much do you know about bone stress injuries? Do you remember your bone physiology? Do you think about the dynamic nature of bone modeling, bone remodeling, and loading when treating your patients with foot and ankle conditions? This issue we have an important message from Stacey Meardon about how to approach your patients at risk for, or suffering from, bone stress injury. Please consider incorporating her clinic-ready recommendations into your patient care.

Enjoy!
Frank

PHYSICAL THERAPY CONSIDERATIONS FOR THE MANAGEMENT OF BONE STRESS INJURY

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Bone stress injuries (BSI) plague physically active populations and are often overlooked by patients and clinicians. Many terms have been used to describe BSI in both the clinic and the literature (eg, shin splints, medial tibia stress syndrome (MTSS), bone edema, stress reactions, stress fracture). Relevant to physical therapists with interest in the foot and ankle, most BSI in exercisers, athletes and tactical athletes occur below the knee, with tibia and metatarsal BSI most common.[1–3] Foot and ankle related BSI with a high rate of complication and delayed or low return to sport include the anterior tibial shaft and tarsal navicular.[4] Bone stress injuries occur due to the failure of bone in response to repetitive mechanical loads that exceed bone strength, causing progressive accumulation of microdamage. Current radiological evidence suggests that BSI severity falls on a continuum, encompassing four grades, ranging from mild periosteal edema (Grade 1) to a visible fracture line (Grade 4); if left untreated, BSI can progress to a complete fracture[5,6] (**Figure**).

Bone stress injuries are debilitating injuries that require time away from exercise, sport, work, and duty; training loss may range from 42 to 127 days and recurrence is common.[4,7] Studies have also shown that 20% or more of BSI are season ending[3] and can lead to medical disqualification from sport[8] and high separation rates in military populations.[9] Patients struggling with severe overuse injuries, including BSI, suffer from lower quality of life measures including uncertainty, fear, stress, increased pressure, altered mood, frustration, low energy, impaired social interaction, anger, and depression.[10,11] Benign terms to describe BSI, like shin splints and MTSS, should be avoided because they may cause clinicians, patients, coaches, and parents to overlook the severity of BSI and delay early intervention.

DYNAMIC BONE REMODELING AND MODELING PROCESSES ARE BSI TARGETS FOR EXERCISE INTERVENTION

Physical therapists are well-positioned to treat BSI as well as to promote bone health across the lifespan in physically active populations. To do so, we need to remember that two exercise driven physiological processes, bone modeling and remodeling, alter bone in distinct ways. Bone remodeling involves coupled action of osteoclastic resorption and subsequent osteoblastic bone formation and acts to renew bone.[12] The remodeling process starts with osteoclast activation and resorption, together lasting approximately 3 to 6 weeks. The resorption of bone associated with remodeling transiently increases the porosity of cortical bone, reducing bone strength and increasing susceptibility to injury. Osteoclast resorption is then followed by osteoblast formation that spans weeks to months.[12] The complete remodeling process lasts 4-6 months, assuming there is no underlying pathology. It is through this ongoing remodeling process that most of the adult skeleton is replaced every 10 years. Bone remodeling can be stochastic or targeted. Stochastic remodeling is a random process associated with osteoclastic resorption without a specific local event and is thought to aid in calcium homeostasis. Targeted bone remodeling, on the other hand, occurs in response to specific local events such as activity related microdamage or osteocyte apoptosis and serves to repair mechanically compromised bone. However, BSI can occur when targeted remodeling at a specific site is outpaced by microdamage accumulation, often referred to as accelerated remodeling (**Figure**). The net result of bone remodeling is bone maintenance or a slight reduction in bone mass.

Bone modeling on the other hand involves the independent actions of osteoblasts and osteoclasts to form or resorb bone, respectively. Even after maturity, bone modeling, predominant during growth, functions to both increase and shape bone.[12] A key stimulus for adaptive formation modeling is bone strain from applied loads, like those experienced with exercise. Exercise induced bone formation on the periosteal surface of long bones increases cortical thickness and cross-sectional moments of inertia, especially during growth and with targeted exercise training in adults.[13] Adaptive formation modeling results in thicker, wider bones with greater resistance to bending and failure. Bone modeling can also enhance trabecular structure by reorienting trabeculae in the direction of applied stresses. Unlike remodeling, the net effect of formation modeling on bone is an increase in bone mass with a little bone going a long way. Additionally, bone modeling does not require prior resorption and can occur over a relatively short period. For instance, bone formation in response to a novel physical training regimen has been seen in young adult females in as little as 8 weeks.[14]

In both modeling and remodeling, newly formed bone and reorganization of bone can lead to increased bone stiffness, strength, and resistance to fatigue. But newly formed bone requires time for mineralization, with complete mineralization requiring at least one year.[12]

AN EXERCISE PARADOX FOR BSI EXISTS

Exercise related loading is a potent stimulus for both damage related repair and bone formation. However, bone loses its sensitivity to mechanical stimuli after 40-100 load cycles.[15] Thus, prolonged exercise has diminishing returns for bone. Additionally, exercise related workloads can lead to accelerated remodeling and contribute to BSI (**Figure**). Because of this paradox, physical therapists need to consider the time course of bone remodeling and modeling when designing interventions. Bone resorption associated with targeted remodeling in response to microdamage may lead to increased susceptibility of BSI, especially in the 3 to 6 weeks following an increase in bone loading characteristics (eg, initiation of physical activity, increase in training load, increase in applied loads). Thus, physical therapists should advocate for strategies that limit accumulation of microdamage such as:

1. Integrating dynamic, novel, short duration, and moderate to high-intensity exercises (eg, plyometric jump training) with periods of rest into training programs to promote adaptive bone formation and bone strength; prime windows of opportunity include adolescence as well as initial training.[15]
2. Incorporating activities that vary the location of bone loading during activity, such as multi-directional sports, to distribute loads throughout the bone and promote adaptive formation and bone strength.[16]
3. Progressively introduce loads to allow for safe participation and adaptive bone formation without bone resorption outpacing formation.
4. Include periods of reduced loads in training plans or periodized training approaches to allow targeted remodeling processes to "catch up."
5. Balance activities associated with higher bone loads with shorter load durations or short intermittent periods of rest when practical. When not practical, ensure adequate time between bouts of exercise for recovery.

RECOVERY FROM BSI REQUIRES MORE THAN REST

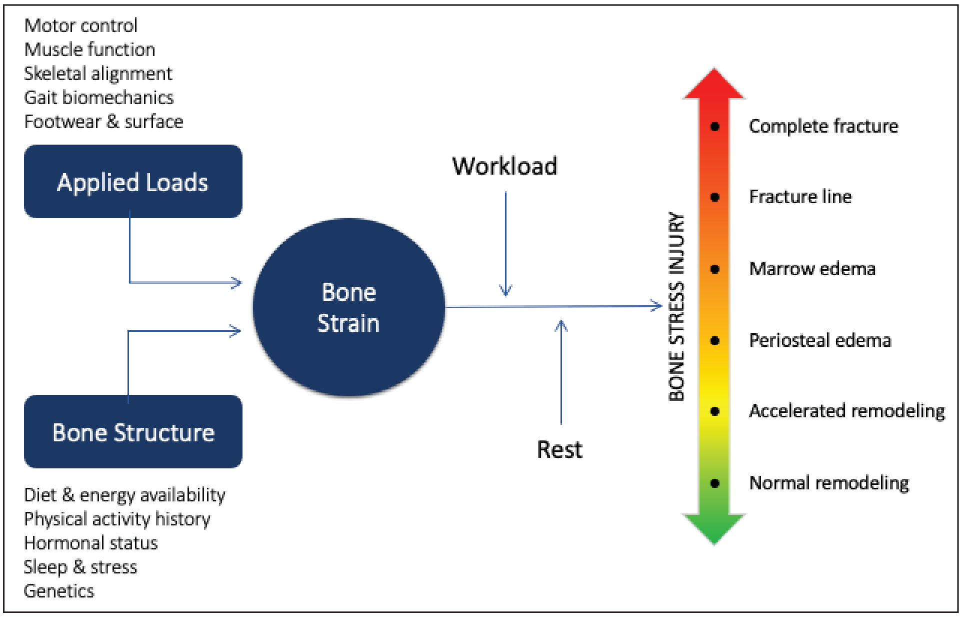
Reduced bone loading is needed to allow bone healing to occur. However, the duration of reduced activity needs to be balanced against deconditioning and disuse related bone loss. Authors suggest that mechanical loading can promote fracture healing and a few bouts of short duration loading can prevent disuse related bone loss.[17,18] Thus, it is important to introduce mechanical loading as soon as safely possible. Unfortunately, consensus on optimal loading following BSI has not been established; many factors should be considered such as underlying physiological processes, risk of complications, fracture recurrence, severity of injury, location of injury, pain, bone strength and energy availability.[4] Current practice suggests that load should be reintroduced progressively (e.g., 5-10% increase in activity-related load/week) and guided by close monitoring of symptoms during, immediately after, and into the next day.[19] Because of this, pain education is important. Load progression should include walk-to-run programs, multi-directional jump training exercises to promote adaptive bone formation and sport-specific training. Exercise dosage should be informed by prior loading history and take into consideration all daily loading activities. Use of monitoring tools that capture both exercise intensity and the number of load cycles may be helpful.

Intervention should also address local muscle function since BSI has been associated with reduced muscle strength characteristics. Further, mechanical and biomechanical interactions between bone and muscle suggest a synergistic relationship between tissues.[20] Thus, treatments that target local muscle may benefit bone and vice versa. Muscular and cardiovascular endurance should also be addressed as symptoms allow since both muscular fatigue and long duration exercise has been associated with increased bone strain.[21,22] Both cross training and interval training may allow for the maintenance of fitness without BSI exacerbation.

Increasing bone load magnitude exponentially reduces the fatigue life of bone. Thus, small reductions in bone loading over repetitive load cycles may have drastic effects on exercise tolerance and minimization of damage accumulation. A 10% reduction in bone load may double the number of load cycles to failure.[23] Rehabilitation following BSI is an opportune time to identify and address gait characteristics (eg, low stride rate, overstriding, narrow step width) that increase bone loads. Additionally, it is important that physical therapists screen, educate, and refer patients for factors that influence bone formation. For example, physical therapists need to screen for energy availability, which is crucial for optimal bone modeling and remodeling processes. Screening tools such as Relative Energy Deficiency in Sport (RED-S) assessment tool can be used to identify individuals and risk.[24] Physical therapists also need to examine sleep, prolonged NSAID use, and stress management.[25]

In closing, physical therapists play a critical role in helping patients with BSI balance adequate time for healing with return to activity. An appreciation of underlying bone physiology can help with exercise prescription to promote bone health and recover from injury. Because of interactions and interrelationships between multiple factors, physical therapists should adopt a holistic and team-based approach to guide rehabilitation after BSI.

Figure. Schematic of the Bone Stress Injury Severity Continuum and Contributing Factors



FOOT & ANKLE

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