Bone Health in Athletes: The Role of Exercise, Nutrition, and Hormones

Marci A. Goolsby, MD,*† and Nicole Boniquit, MD‡

Context: The health of the skeletal system is important for athletes young and old. From the early benefits of exercise on bones to the importance of osteoporosis prevention and treatment, bone health affects the ability to be active throughout life.

Evidence Acquisition: PubMed articles dating from 1986 to 2016 were used for the review. Relevant terms such as keywords and section titles of the article were searched and articles identified were reviewed for relevance to this article.

Study Design: Clinical review.

Level of Evidence: Levels 1 through 4 evidence included.

Results: There is strong evidence that exercise benefits bone health at every age and is a critical factor in osteoporosis prevention and treatment. Vitamin D, calcium, and hormones play vital roles in ensuring optimal bone health. When there is an imbalance between exercise and nutrition, as seen in the female athlete triad, bone health is compromised and can lead to bone stress injuries and early osteoporosis. Both of these can lead to morbidity and lost time from training and competition. Thus, early recognition and appropriate treatment of the female athlete triad and other stress fracture risk factors are vital to preventing long-term bone health problems.

Conclusion: To optimize bone health, adequate nutrition, appropriate weightbearing exercise, strength training, and adequate calcium and vitamin D are necessary throughout life.

Keywords: bone health; stress fractures; exercise; vitamin D; hormones

OVERVIEW OF BONE

The health of the skeletal system is a critical part of the overall health of the athletic population. Bone health can be affected starting in utero where maternal nutrition and medications can affect the fetal skeleton. Bone mineral density (BMD) peaks in early adulthood and declines after menopause in women, and is largely influenced by genetics. However, a variety of other modifiable factors affect bone health, such as exercise, diet, smoking, alcohol, medications, and calcium intake. Adolescence and young adulthood are the most beneficial times for long-term bone density gains, with nearly 90% of peak bone mass gained by age 18 years. However, it is also the most susceptible time, when negative consequences can occur from eating disorders, poor nutrition, hypoestrogenism, and inadequate calcium intake. Physical activity plays a key role, and benefits of bone loading in childhood and adolescence continue into adulthood, where the goal is to maintain bone mass. Maintenance of bone mass can reduce fracture risk by 50% to 80%. In older adults, the goals for exercise are fall prevention and ensuring safe exercise with modifications for those with osteoporosis.

Understanding the benefits of exercise on bone health requires knowledge of bone composition, formation, and adaptation. The adult human skeleton is composed of 80% cortical bone and 20% trabecular, or cancellous, bone. Cortical bone is dense, solid, and surrounds the marrow space, whereas trabecular bone consists of a honeycomb-like network of trabecular plates and rods distributed throughout the bone marrow compartment. Mechanotransduction refers to bone's recognition of and response to loading, with mechanoreceptors primarily on osteocytes, responding to fluid moving in bone's...
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DXA scans that show similar BMD measurements. TBS values tend to be lower in postmenopausal women and in men with previous fractures compared with their nonfractured peers. The advantage of TBS is that it may predict fracture risk in postmenopausal women and is associated with fracture risk in individuals with conditions related to reduced bone mass or bone quality.

**EFFECTS OF EXERCISE ON BONE**

Weightbearing activity has beneficial effects on bone health throughout life. Being sedentary is a known risk factor for osteoporosis, and physical activity is the only intervention that both increases bone mass and strength and reduces the risk of falls. It is best if exercise involves loading in discrete bouts with recovery in between and is most beneficial during skeletal growth. Exercise should be of high-strain magnitudes and/or rates, such as jumping for the lower body and racquet sports for the upper body. To achieve maximum benefits, exercise should:

- be dynamic, not static
- achieve adequate strain intensity
- consist of discrete, intermittent bouts
- include variable loading patterns
- be supported by optimal nutrition
- include adequate intake of calcium and vitamin D.

Exercise causes larger improvements in bone strength than can be measured by BMD, as new bone formation is often at the bone surface. A 5.4% increase in BMD is equal to a 64% increase in ultimate force and 94% increase in energy to failure. Weightbearing activity was found to have a profound impact on BMD in female athletes, with site-specific mechanical loading significantly affecting bone accrual. Both amenorrheic and eumenorrheic athletes were found to have greater total cross-sectional area, trabecular area, and cortical perimeter compared with nonathletes at the distal tibia.

**OSTEOPOROSIS**

Low bone mass increases the risk for fractures, leading to significant morbidity and mortality. In the United States, 52% of adults older than 50 years have low bone mass at the femoral neck or lumbar spine and 9% meet the diagnostic criteria for osteoporosis at 1 or both sites. There are 1.5 million people in the United States annually who sustain an osteoporotic fracture. Mortality increases 2.8 to 4 times during the first 3 months after a hip fracture. Thus, it is critical that measures are taken to prevent and treat osteoporosis.

The American College of Sports Medicine recommends that children and adolescents perform impact activities and moderate intensity resistance training at least 10 to 20 minutes twice a day, 3 days a week. The gains in bone density achieved through exercise in childhood are maintained through adulthood. The goal of exercise in adulthood is to maintain BMD, as it is unclear whether density can be increased with exercise in adulthood. However, there is good evidence that exercise can decrease risk of fracture. For adults, the American College of Sports Medicine recommends weightbearing endurance and plyometric exercise 3 to 5 times per week, and resistance exercise of moderate to high loading 2 to 3 times per week for a total of 30 to 60 minutes per day. In elderly patients, modifications may be necessary to ensure safety, but exercise should continue to improve balance and prevent falls.

Studies have shown that a variety of different types of exercise can be beneficial, including impact cardiovascular exercises and resistance training; the most beneficial exercise is a combination of different activities. Nonweightbearing high-force exercise, such as progressive resistance strength training for the lower limbs, has the most impact on femoral neck BMD, whereas the most effective intervention for BMD at the spine was a combination exercise program. Studies have shown that exercise reduces the risk of hip fracture in older women and decreases the overall incidence of fractures, despite the lack of BMD changes. This may be explained by animal studies that show an increase in bone strength that far exceeds the changes seen in BMD. Therefore, activities in patients with osteoporosis should include muscle-strengthening and balance exercises to reduce fall risk.

**ROLE OF VITAMIN D AND CALCIUM**

Vitamin D has a significant impact on bone health, immune function, and physical performance. In the deficient state, the athlete may be at an increased risk for stress fractures, respiratory infections, and muscle injuries. It is estimated that 1 billion people, including the elderly, young adults, and children, are vitamin D-deficient or insufficient. Although there is debate about the optimal serum levels of 25-hydroxyvitamin D [25(OH)D], vitamin D deficiency is defined by most experts as a total 25(OH)D level of <20 ng/mL. Vitamin D insufficiency is defined as a level of 20 to 31 ng/mL, and a level of ≥32 ng/mL demonstrates sufficient levels. The prevalence of vitamin D insufficiency and deficiency in athletes is about 50% overall with a higher incidence in the winter and spring, indoor sports, and mixed sports. In a study of NCAA athletes, the prevalence was 33.6%, despite taking place in southern California during the summer months. The causes of vitamin D deficiency can be multifactorial, including reduced skin synthesis, absorption of dietary vitamin D, and acquired and heritable disorders of vitamin D metabolism. The main cause of vitamin D deficiency in the athletic population is the direct result of decreased ultraviolet B (UVB) radiation absorption into the skin, leading to decreased cutaneous synthesis of vitamin D. This has the greatest impact on indoor athletes and those who live and train in latitudes furthest from the equator. The lack of UVB absorption has a similar effect on dark-skinned athletes with increased skin.
levels are increased, which triggers an increase in osteoclastic
stones or cardiovascular events as seen with artificial forms of
products, however, does not seem to pose risks for kidney
supplementation. Consuming calcium in diet, such as dairy
daily. Patients should be informed of potential harm with
and cardiovascular events, even in dosages as low as 500 mg
increased risks of adverse effects, particularly kidney stones
Intake of calcium through diet is preferable considering the
height measured by jump mechanics.101

25(OH)D3 levels and muscle power, force, velocity, and jump
aged 12 to 14 years, there is a direct correlation between
and calcium supplementation in reducing the risk of
fractures.15,18,42 The role of calcium in strengthening bones is
appear reversible with vitamin D supplementation.9 In girls
aged 12 to 14 years, there is a direct correlation between
25(OH)D3 levels and muscle power, force, velocity, and jump
height measured by jump mechanics.101

There still exists controversy over the benefit of vitamin D
and calcium supplementation in reducing the risk of
fractures.15,18,42 The role of calcium in strengthening bones is
unclear. On one hand, Americans have among the highest
calcium intake in the world, but also one of the highest rates
of osteoporosis.64 The recommendations for daily calcium
intake are 1300 mg for adolescents, 1000 mg for women aged
19 to 50 years, and 1200 mg for women older than 50 years.31
Dietary dairy is the best source of calcium as not only is it the
most bioavailable but is also an energy-dense food source.62
Intake of calcium through diet is preferable considering the
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stones or cardiovascular events as seen with artificial forms of
calcium supplementation.19,32

On the other hand, both calcium and vitamin D
supplementation can decrease the incidence of stress fractures,
as seen among female military recruits.55 In older populations
(age ≥65 years), high-dose vitamin D supplementation (>800 IU
daily) prevented hip and nonvertebral fractures.15 A recent study
of professional football players also showed a higher incidence
of fractures in vitamin D-deficient players and, perhaps,
decreased performance.66

**IMPACT OF HORMONES ON BONE HEALTH**

Estrogen plays an important role in skeletal homeostasis, with
well-recognized benefits on BMD. At the cellular level, estrogen
affects both osteoclasts and osteoblasts. It inhibits bone turnover
and maintains balance between bone resorption and
formation.80 Estrogen acts on osteoblasts and osteoclasts in a
receptor-mediated fashion and has indirect effects on other
hormones, including calcitonin, parathyroid hormone,
cytokines, and growth factors.5,60

Adolescence is a particularly crucial period for skeletal
development. Because of the significant impact puberty has on
bone growth, there is up to a 50% increase in total body bone
mass between the ages of 12 and 18 years.80 Increases in
growth hormone, insulin-like growth factor 1, and estrogen that
occur between Tanner stages 2 and 4 coincide with maximal
rates of bone mineral gains. Testosterone and estradiol are
known to have positive effects on bone health; however,
absence of these hormones is linked to osteoporosis.61,104 These
hormones protect against bone loss by having antiapoptotic
effects on osteocytes and osteoblasts, and apoptotic effects on
osteoclasts.60 In addition, these hormones slow the rate of bone
remodeling, and the number of remodeling cycles
decreases.60,104

In the athletic population, use of hormones in treatment of
amenorrhea, oligomenorrhea, and low bone density has been
controversial or inconclusive.50,35,55,78 The impact of oral
hormones on insulin-like growth factor 1 in the liver may
negate the benefit of estrogen on bone.33,35,78 Insulin-like growth
factor 1 is a bone trophic hormone and oral estrogen decreases
its systemic concentration but transdermal estrogen does not,
thus leading researchers to investigate the effects of transdermal
estrogen on BMD.50,70,103 When low BMD is from low energy
availability and a hypoestrogenic state as seen in the female
athlete triad (Triad), the emphasis for treatment should be to
improve BMD and resume normal menses through nutritional
and behavioral changes. However, if bone density remains low
despite at least 1 year of treatment, transdermal estrogen
should be considered.55

Other hormonal medications have an impact on bone health,
such as depot medroxyprogesterone acetate (Depo-Provera)
injectors for birth control and hormone replacement therapy
(HRT) in menopausal treatment. The mechanism for loss in
BMD among Depo-Provera users is estrogen deficiency because
of suppression of the hypothalamic-pituitary-ovarian axis
without exogenous estrogen replacement. A higher body weight correlates with higher BMD, regardless of treatment with hormonal contraception, suggesting that body weight and body fat may override potential detrimental effects of Depo-Provera. HRT improves BMD, decreases fracture risk, and improves symptoms in postmenopausal women and was a more commonly used therapy for osteoporosis prior to the publication of the Women’s Health Initiative and the Million Women Study, which raised some concerns about potential risks of breast cancer, cardiac disease, and stroke. Because of these concerns and the availability of other osteoporosis medications, estrogen has a role but is no longer a first-line agent for postmenopausal osteoporosis.

The Triad was originally described in 1992 as 3 interrelated components: disordered eating, amenorrhea, and osteoporosis. This definition has expanded to now describe a spectrum of pathology that includes less severe forms of these 3 factors. The goal of describing the Triad as a spectrum is that athletes with subclinical versions of these factors can be identified and treated early before negative consequences—such as bone stress injuries, traumatic fractures, early osteoporosis, cardiovascular issues, and infertility issues—can occur. The crux of the Triad is low energy availability with or without disordered eating. Low energy availability often causes menstrual dysfunction and hypogonadism, leading to negative effects on bone health and endothelial cell dysfunction. Bone stress injuries, which include stress reactions and fractures, are more often seen in athletes with menstrual irregularities and/or low BMD. Athletes with amenorrhea are 2 to 4 times more likely to suffer a stress fracture than eumenorrheic subjects. In a study of college athletes, the lower the BMD the longer the recovery from a stress injury. The risk of incurring a stress injury increases as the number of Triad-related risk factors increases. Although the Triad is specifically describing the syndrome seen in women, a parallel syndrome is seen in men with low energy availability, hypogonadism, and low BMD, with further research needed in this area.

The fact that the Triad is a spectrum of disease makes determining prevalence challenging. Up to 15.9% of athletes have all 3 most severe components of the Triad. The prevalence increases when evaluating those with less severe components or those with 1 or 2 components. Estimated prevalence of menstrual disturbance in female athletes is up to 60%, eating disorder/disordered eating is up to 89.2%, and low BMD is up to 39.8%. Early detection is critical to prevent the negative consequences of the Triad. A series of questions has been suggested as part of screening questionnaires used for the preparticipation evaluation (Table 1). It is important to recognize that normal menses does not mean the Triad may not be present, so all factors of the Triad need to be investigated. Among high school athletes, those taking hormonal contraceptive pills were more likely to have disordered eating despite the same injury and menstrual patterns as those not taking hormonal contraceptive pills. If there are any concerns about the responses to the questions, further in-depth evaluation using a team of health professionals is recommended. This team should include the team physician, sports dietitian, and mental health professionals, as indicated. The physical examination should include height, weight, body mass index (BMI), and signs of eating disorders (lanugo, parotid gland enlargement, calluses on knuckles, and tooth enamel erosions). There are a variety of ways to assess energy availability and an experienced sports dietitian or exercise physiologist can assist. Energy availability is defined as energy intake (kcal) minus exercise energy expenditure (kcal) divided by kilograms of fat-free mass or lean body mass. These components can be difficult to measure outside the research setting but estimates and less precise measurements can be done and an energy availability calculator is available.

### FEMALE ATHLETE TRIAD

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### Table 1. Screening questions for the female athlete triad

- Have you ever had a menstrual period?
- How old were you when you had your first menstrual period?
- When was your most recent menstrual period?
- How many periods have you had in the past 12 months?
- Are you presently taking any female hormones (estrogen, progesterone, birth control pills)?
- Do you worry about your weight?
- Are you trying to or has anyone recommended that you gain or lose weight?
- Are you on a special diet or do you avoid certain types of food or food groups?
- Have you ever had an eating disorder?
- Have you ever had a stress fracture?
- Have you ever been told you have low bone density (osteopenia or osteoporosis)?

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on the Female Athlete Triad Coalition website (http://www.femaleathletetriad.org/calculators). Functional hypothalamic amenorrhea is the disruption of the hormonal axis function secondary to low energy availability and is a diagnosis of exclusion. Laboratory analysis should include tests to evaluate for pregnancy, thyroid dysfunction, hyperprolactinemia, primary ovarian failure, and other endocrine disorders.33 Evaluation with a DXA scan should be considered in the following instances:

- diagnosis of an eating disorder
- BMI ≤17.5 kg/m², <85% estimated weight, or recent weight loss of ≥10% in 1 month
- menarche ≥16 years
- current or history of <6 menses over 12 months
- 2 prior bone stress injuries, 1 high-risk stress injury, or a low-energy fracture
- prior Z-score ≤−2.0.

If multiple risk factors are present but not as significant or the athlete is taking medications known to negatively impact the bone, the physician should also consider ordering a DXA scan (Table 2).33

| Table 2. Medications with adverse effects on bone |
|--------------------------------------------------|
| Aluminum-containing antacids                       |
| Antiseizure medicines (ie, phenytoin)              |
| Aromatase inhibitors (ie, anastrozole)             |
| Cancer chemotherapy agents                         |
| Glucocorticoids (ie, prednisone)                   |
| Gonadotropin-releasing hormone (ie, leuprolide acetate) |
| Heparin                                            |
| Lithium                                            |
| Medroxyprogesterone acetate injectable solution    |
| Proton pump inhibitors                             |
| Selective serotonin uptake inhibitors              |
| Tamoxifen                                          |
| Thiazolidinediones                                 |
| Thyroid medication in excess                       |

The best treatment for the Triad is prevention. Work must be done to continue to change the culture in some sports as it relates to weight and body image. Creating a healthy approach to exercise and nutrition at home and in schools will hopefully achieve this. Screening to identify those athletes with the Triad or at risk for the Triad will allow early intervention to minimize risk to the athlete. Treatment of the Triad is focused on correcting the low energy availability and requires a multidisciplinary approach in which education of the athlete is the key component. Nutrition counseling, exercise counseling, and psychological therapy may all be necessary aspects of treatment. Restoration of weight and resumption of normal menses are the main goals of treatment and are important in preventing further bone loss.33,71 The majority of athletes can be treated successfully with a nonpharmacologic approach, but in those with osteoporosis and/or history of multiple fractures who do not respond to nonpharmacologic treatment for 1 year or who continue to fracture, pharmacologic treatment should be considered. To address the hypoestrogenic state, estrogen replacement can be considered and has been shown to have beneficial effects on bone mass when given via the transdermal route. Combined oral contraceptive pills do not improve bone density in young women.30,102 For athletes in whom the Triad has been diagnosed, clearance and return to play can be challenging, and clinicians want to ensure participation is safe for the athlete. Guidelines using a risk stratification tool have been described in the 2014 Female Athlete Triad Consensus Statement on Treatment and Return to Play of the Female Athlete Triad.33

**STRESS INJURIES**

Bone stress injuries occur over a spectrum, which encompasses stress reactions and stress fractures. They occur because of a disturbance in the equilibrium between osteoblastic bone formation and osteoclastic bone resorption. If bone is unable to withstand repetitive mechanical stresses and edema (reaction), fracture can occur. Not all stress fractures are the same; cancellous bone stress fractures occur more often in patients with osteopenia, compared with cortical stress fractures.67,76 More severe stress fractures by magnetic resonance grading are correlated with lower BMD. High-risk stress fractures such as those seen in the sacrum, pelvis, and femoral neck are associated with more risk factors such as the Triad.76 Bone stress injuries are a common cause of missed training and competition and have a higher prevalence in track and field athletes and military recruits. The prevalence of stress fractures is 0.7% to 21% in athletes.12 Stress injuries of the foot and lower leg are most common,86,88 but they can occur in any bone that is subjected to repetitive stress. Risk factors for stress injuries are often described as intrinsic and extrinsic (Table 3). Specifically,
factors of the Triad, such as disordered eating,13 menstrual irregularities,8,13 and low bone density13,74 are associated with stress injuries (Figure 2). Runners with oligomenorrhea were 6 times more likely to sustain a stress injury.13 Stress injuries can be diagnosed clinically but imaging is often used to assist with the diagnosis of certain stress injuries. Plain radiographs may be normal, particularly in certain stress injuries such as those of the femoral neck (Figure 3), and magnetic resonance imaging (MRI) or bone scan may be indicated to diagnose the stress injury. MRI grading can be helpful for prognosis as well4,72,76; in college athletes, the higher the MRI grade, the longer the recovery.76

The focus of stress injury treatment is on minimizing weight-bearing activity to allow healing as well as identification and treatment of underlying risk factors. Plain radiographs may be normal, particularly in certain stress injuries such as those of the femoral neck (Figure 3), and magnetic resonance imaging (MRI) or bone scan may be indicated to diagnose the stress injury. MRI grading can be helpful for prognosis as well4,72,76; in college athletes, the higher the MRI grade, the longer the recovery.76

For stress fractures with delayed healing and/or in the setting of low BMD, case studies describe adjunctive medications (nasal calcitonin,43 bisphosphonates,69,92,94 and recombinant parathyroid hormone Forteo)92 but the evidence of their effectiveness and safety in human clinical trials is lacking. In addition, bisphosphonates have teratogenic effects that last for many years in the bone so they should be avoided in women in their childbearing years. There has been some promising evidence for recombinant parathyroid hormone improving BMD, bone mineral content, and stress fracture healing in animal studies but further research is needed in humans.92 External bone stimulators have also been used, although human evidence is lacking for their effectiveness in stress fractures and data are primarily found in studies of traumatic fractures.27,99

**CONCLUSIONS**

Exercise plays a vital role in achieving optimal bone health in athletes. Exercise has a variable impact at different stages of life, and adolescence is a critical time during bone mass development. To prevent osteoporosis and bone stress injuries, adequate calcium and vitamin D intake and a healthy balance between exercise and nutrition are necessary. The components of the Triad are associated with lower BMD and stress injuries. Therefore, when a stress injury is diagnosed, part of the treatment plan should include evaluation for and treatment of risk factors to identify those who could carry negative consequences on bone health.
Figure 3. Imaging studies of a right compression-sided femoral neck stress fracture in a 26-year-old female runner with the female athlete triad. Anteroposterior pelvis radiograph (a) does not show any abnormality. Coronal inversion recovery (b) and proton density–weighted (c) magnetic resonance images show bone marrow edema with a fracture line that involves approximately 50% of the diameter of the neck. A repeat coronal proton density–weighted magnetic resonance imaging done 6 weeks later (d) shows interval healing with decreased fracture line.

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