Osteoporosis and Physical Activity

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HIGHLIGHT

"Bone health is promoted through regular weight-bearing physical activities that use muscular strength and power, and exert force on the skeleton above normal amounts."

INTRODUCTION

The National Osteoporosis Foundation (NOF) has defined osteoporosis as a disease characterized by low bone mass and microarchitectural deterioration of bone tissue leading to enhanced bone fragility and a consequent increase in fracture risk. In other words, osteoporosis is the loss of bone tissue that makes bones weaker. It has been projected that over 5 million fractures of the hip, spine, and wrist will occur in women over the age of 45, which will account for more than $45 billion in direct health care costs over the next ten years (Chrischilles, Shireman, & Wallace, 1994). This is a conservative estimate of the future public health impact of osteoporosis, since the projections are based on only three fracture sites and limited to females. No doubt the estimate would be greater if it included men, who also are at risk of osteoporosis as they grow older.

In addition to the financial burden attributed to this disease, osteoporosis has a profound effect on the quality of life of older individuals. Those afflicted typically experience reduced mobility, pain, loss of independence, and psychological distress associated with postural disfigurement and the fear of additional fractures. Hip fractures are the most severe fractures since they carry the highest incidence of morbidity and mortality. The postural abnormality associated with vertebral fractures results in reduced cardiovascular capacity and affects other internal organs due to compression of the chest and abdominal regions. In order to define effective preventive strategies, it is important to determine the lifestyle factors that influence fracture risk. The two primary determinants of fracture risk are low bone mass and falls.

Physical activity has been proposed as one strategy to reduce fractures by increasing bone mass and by preventing falls through improved functional ability. Although the mechanism by which exercise increases bone mass is not clear, it likely influences bone directly through mechanical forces (loading) transferred to bone. Bone responds to changes in mechanical loading and the regulation of bone strength is a function of the loads to which the skeleton is exposed. The most striking examples of this adaptation are the reports that demonstrate marked bone loss in the absence of weight-bearing activity, such as occurs in space travel and prolonged bed rest (Mack et al., 1967; Nishimura et al., 1994). Conversely, many reports have shown that bone mass among physically active individuals and athletes is significantly higher compared to their nonactive and nonathletic counterparts. Some studies that have imposed significant mechanical forces via exercise intervention report positive effects on bone mass, although the magnitude of effect is much less impressive than would be predicted from studies on athletes and active individuals. Therefore, the ideal exercise program that maximizes bone response remains elusive. Evidence is accumulating to suggest, however, that exercise that increases muscle strength, mass, and power, may provide the best osteogenic stimulus. Activities of this type provide additional skeletal protection in the older adult by preventing falls, which are highly related to the incidence of fractures, particularly at the hip.

This review presents the recent literature in the field and provides recommendations for exercise design that may aid in fracture prevention. In this review, the terms "bone mass" and "bone mineral density (BMD)" will be used as synonyms.

PHYSICAL ACTIVITY AND BONE MASS

Physical activity transmits loads to the skeleton in two ways: by muscle pull and by gravitational forces from weight-bearing activity. It is generally assumed that a high level of activity corresponds to a high level of mechanical loading. However, despite the intensity of muscular activity associated with competitive swimming, studies comparing athletic groups have demonstrated that swimmers generally have BMD values lower than those of nonathletic controls (Taaffe et al., 1995). Therefore, activities that require full support of body weight (i.e., those that are performed on the feet) are recommended if skeletal response is a desired outcome of exercise participation. Sports with unilateral activity, such as tennis, continue to provide the best representation of the positive effects of exercise on bone in humans (Huddleston et al., 1980; Kannus et al., 1994). These studies have demonstrated greater BMD in the dominant playing arm vs. the nondominant arm across different age groups. However, most forms of activity are not as easily characterized by such specific, localized loading patterns.

Other indicators that physical activity exerts a positive influence on the skeleton is the finding that certain measures of physical fitness are correlated with BMD. Specifically, body composition and muscular strength exhibit positive associations with bone mass. Investigations of BMD and body composition have arisen out of the common finding that body weight is associated with bone density. Research has attempted to specify which aspect of body composition, lean (muscle) or fat mass, is the best predictor of bone mass. Muscle directly attaches to bone and may influence the skeletal system via this mechanism, while fat mass contributes to body weight in a nonspecific manner. It has been proposed that fat mass has the potential to increase circulating levels of estrogen, although this explanation for its beneficial influence on bone has yet to be established. Associations between both fat and lean mass and BMD have been demonstrated (Reid, Plank, & Evans, 1992; Sowers et al., 1992). Although fat mass has been associated with bone and can provide cushioning in the fall-prone elderly, there are known health problems associated with excess body fat (e.g., cardiovascular disease, type II diabetes). On the other hand, adequate muscle mass is necessary for optimal function throughout the life span and muscular atrophy that accompanies the aging process is associated with falling and fracture. Therefore it is prudent to recommend that a fracture prevention program include activities that encourage muscle mass development.

Mechanical forces are directly applied to bone by muscular attachments and individuals with high muscle strength are able to generate large forces during contraction. Thus, muscle strength is a measure of physical fitness that has been studied with respect to skeletal health. Research has shown that the relationship between muscle strength and bone demonstrates site-specificity. Strength of the hip muscles has been related to hip BMD, and grip strength has been associated with forearm BMD (Snow-Harter et al., 1993; Snow-Harter et al., 1990). The contribution of muscle strength to BMD in various cross-sectional studies has ranged from 9 to 38% in nonathletic adults. Since approximately 60–80% of bone mass is estimated to be genetically determined, the relationship between muscle strength and bone is not trivial and again points to the importance of the muscular system with respect to bone health.

Research has demonstrated that male and female athletes who participate in sports that require muscular strength and power (e.g., weight lifting, gymnastics, wrestling) exhibit higher bone mass than those whose sports involve primarily muscular endurance (e.g., distance running, triathlon) (Robinson et al., 1995). Information on the loading characteristics of various activities suggests that walking and slow running provide loads equal to or slightly higher than body weight alone at the spine. In comparison, forces at the spine have been estimated to be five to six times body weight while weight lifting (Granhad, Jonson, & Hansson, 1987). Jumping associated with gymnastics training may elicit forces as high as 10 to 12 times body weight.

The research on athletes and the size of the load for a specific sport suggests that the skeleton's response to mechanical loading depends on the *magnitude* of the force. In practical terms, the skeleton must encounter forces that are *greater* than those it experiences on a day-to-day basis. Even though walking is a weight-bearing activity, its ability to evoke a skeletal response is limited to the older adult who was previously bedridden and unable to ambulate for a period of time. On the other hand, one who performs activities of daily living without assistance will be in a weight-bearing posture much of the day. For this person, walking as an exercise will not exceed the loading threshold of daily activities and therefore will not improve bone mass.

Exercise intervention studies have attempted to introduce various exercise programs in humans to determine the best exercise prescription for bone health. The results of these studies are equivocal. While some reports indicate that BMD increases slightly with exercise, some report no change or slight decreases. In order to detect changes in bone mass, an intervention must be several months in duration, depending on the age group and type of program (six months minimum). Relative to other exercise interventions, these are long time intervals (e.g., muscular strength increases can be observed in eight weeks). Over the life span, however, these time intervals are relatively short. This may be one reason why remarkable changes have not been observed within the time frame of training studies. In addition, the expected magnitude of skeletal response is much less than that observed in the muscular system. To illustrate, muscular strength improvements on the order of 50–100% during the course of a resistance training program are not unusual, especially if initial values were low. A 1.5% increase in bone mass over a period of nine months is meaningful, since average rates of loss are approximately 0.5–1% per year. To date, most exercise studies have not designed their exercise training programs according to the principles of training. This may be the main reason why many studies have observed minimal or no training effects on the skeleton (Drinkwater, 1994). The application of these principles to bone loading is outlined in Table 12.1.

TABLE 12.1
Principles of training.

Specificity	The impact of the training should be at the bone site of interest since loading seems to have a localized effect.
Overload	The training stimulus must include forces much greater than that afforded by habitual activity.
Reversibility	In the absence of the training stimulus, the positive effect on bone will be lost.
Initial values	Individuals with low BMD will have the greatest potential to gain from increased mechanical loading.
Diminishing returns	Each individual's biological ceiling determines the extent of adaptation to the training.

PREVENTION STRATEGIES THROUGHOUT THE LIFE SPAN

Bone is a dynamic tissue that is constantly undergoing remodeling activity, a function of bone cells, during which old bone is removed and new bone is formed. The factors that determine the level of bone cell activity are mechanical loading, calcium intake, and reproductive hormones. Strategies to decrease risk for osteoporotic fracture should take these factors into consideration throughout the life span since bone mass in the older adult is a product of the amount of bone acquired during growth and subsequent rates of loss during adulthood.

Physical activity has been shown to be an important contributor to bone mass in children prior to adolescence (Slemenda et al., 1991). In addition, this group should have adequate calcium intake so that the necessary blocks for building bone mineral are present during growth. It has been proposed that young bone may be more responsive to mechanical loading than old bone (Forwood & Burr, 1993). Given that approximately 60% of the final skeleton is acquired during adolescence, one preventive strategy is to maximize skeletal loading during this rapid phase of growth. It is also important to consider reproductive endocrine status at this time of life. The negative effects of abnormally low estrogen on BMD in amenorrheic women with a high volume of physical training and very low body weight (primarily distance running and ballet dancing) are well documented (Drinkwater et al., 1984). These effects are even more dramatic in amenorrheic women with anorexia nervosa. Although there is little if any documentation in men, abnormally low testosterone levels are theoretically detrimental for bone.

Preventive strategies in adults are generally aimed at maintaining bone mass or reducing the rate of loss. However, recent studies on young adult women indicate that physical activity may play an important role with respect to the capacity to increase bone mass after growth has stopped (Recker et al., 1992; Bassey & Ramsdale, 1994). Recker and colleagues observed increases in spine BMD over a period of five years in a large group of women in their twenties. The increases were related to self-selected physical activity patterns. Bassey and Ramsdale (1994) administered high- and low-impact exercise programs to young women for six months and observed BMD increases at the hip in the high-impact group only. The authors note that small improvements in bone mass in young to middle adulthood may result in quite significant reductions in risk for osteoporotic fracture in later years. It is important to note that BMD increases with physical activity are likely to be most dramatic in young adulthood when bone appears to be more responsive to mechanical loading. In addition, loading characteristics must be substantial, as demonstrated by the high-impact activity administered by Bassey and Ramsdale (1994), which included jumping. Adequate calcium intake and maintenance of normal circulating levels of reproductive hormones are still important factors for optimal bone health in adulthood. However, since growth has ceased, recommendations for calcium intake are slightly lower than in adolescence.

Older adults face multiple challenges with advancing age. Age-related reductions in bone mass, muscle strength and power, and postural stability make this group at highest risk for fracture. Impaired musculoskeletal function and dynamic balance associated with aging and disuse ultimately result in decreased mobility. In addition, these declines in musculoskeletal function have been associated with an increase in falls and incidence of hip fracture. Vandervoort et al. (1990) report that once function has declined to the point where mobility is significantly reduced, older individuals may refuse to ambulate due to a fear of falling, which is the beginning of a downward spiral that ultimately results in loss of independence. This situation, in which very few physical attempts are made, leads to marked reductions in strength and power of the lower extremities, which have been specifically linked to fall risk. Although bone mass is a major risk factor for osteoporosis, falls and their severity are highly related to fractures in the elderly. In fact, 90% of all hip fractures occur as a result of a fall (Melton, 1993).

Falls are caused by many different factors. Epidemiological research has consistently found that lower limb strength, reaction time, sensory impairment, and postural instability are important risk factors for falls. Greenspan et al. (1994) have proposed that not all falls are potentially injurious and that fall *severity* in combination with bone mass at the hip are the two primary determinants of hip fracture in ambulatory elderly. Specifically, those who fall to the side and have no ability to alter fall direction or speed of impact and land directly on the hip, are more likely to fracture, particularly if BMD at that site is low (Hayes et al., 1993). The link of muscular strength and power to fall risk is most logically in the stabilization and control required for voluntary movements as well as for the ability to recover from a stumble. One study determined that leg extensor (quadriceps) power in older men and women was the best predictor of functional performance (Bassey et al., 1992).

Strategies to prevent fracture in older adults must target bone mass as well as factors associated with falls. Several studies have observed beneficial effects of weight training in older populations including increased bone mass, muscular strength, power, dynamic balance, and functional independence. Thus, this may be the best choice of exercise training at this stage in the life span. Most research has focused on machine-based training (e.g., Universal Gym, Nautilus), which requires a seated posture for lower body exercises. While this isolates muscle groups in the legs, it effectively reduces loads at the hip and does not require postural control and balance. To encourage optimal function in a standing posture, older adults should be encouraged to perform exercises such as stepping and rising from a chair. These exercises target muscle groups and actions important for everyday function. While it may seem dangerous for older adults to engage in this type of training, resistance training has proven successful among nursing-home residents, even among quite old adults. The benefits of participation clearly outweigh the risks of immobility, decreased function, and increased likelihood of falls and fracture.

Assessing Your Risk for Osteoporosis

For each of the following questions, check either yes or no.

	Yes	No
1. Do you have a family history of osteoporosis? (Have any of your relatives broken a wrist or hip or had a dowager's hump?)		
2. Did you go through menopause or have your ovaries removed by surgery before age 50?		
3. Did your menstrual periods ever stop for more than a year for reasons other than pregnancy or nursing?		
4. Did your ancestors come from England, Ireland, Scotland, Northern Europe, or Asia, or do you have a small, thin body frame?		
5. Have you had surgery in which a part of your stomach or intestines was removed?		
6. Are you taking or have you taken drugs like cortisone, steroids, or anticonvulsants over a prolonged period?		

7. Do you have a thyroid or parathyroid disorder (hyperthyroidism or hyperparathyroidism)?

8. Are you allergic to milk products or are you lactose intolerant?

9. Do you smoke cigarettes?

10. Do you drink wine, beer, or other alcoholic beverages daily?

11. Do you do less than one hour of exercising such as aerobics, walking, or jogging per week?

12. Have you ever exercised so strenuously that you had irregular periods or no periods at all?

13. Have you ever had an eating disorder (bulimia or anorexia nervosa)?

If you answered "yes" to many of these questions, you may be at an increased risk for osteoporosis.

CONCLUSIONS

Exercise may benefit the skeleton and reduce osteoporosis and fracture risk in the following ways: (1) increase bone mass up to and through adolescence, which will result in higher BMD levels across the life span; (2) improve and maintain bone density during early adulthood; and (3) reduce or slow the rate of age-related loss during middle and older age. In order to have an effect on bone, exercise must be different from daily activities, that is, an *overload* must be applied to the skeleton. It is important to remember that physical activity has not been shown to offset the transient increase in bone loss resulting from estrogen deficiency that is observed in the first five to seven years past menopause. Although still uncertain, the gap is beginning to narrow with respect to the types and amount of activities that confer the best osteogenic stimulus. Participation in activities of high load and low repetitions, which increase muscle strength and power, may ultimately prove to be the most beneficial to bone mass. Research to quantify forces from activities that promote strength and power will substantiate these predictions and the models should be evaluated in populations at different stages of skeletal development.

The importance of building lower extremity strength and cardiovascular health cannot be over- emphasized with respect to fall prevention and general health. Low bone mass is a primary risk factor for fractures, with 90% of hip fractures occurring as the result of a fall. Perhaps the most significant benefit of participation in exercise relates to improvements in neuromuscular function. Sound neuromuscular function is essential for both static and dynamic postural stability. The ability to avoid an obstacle, recover from a stumble, or alter the direction of a fall may significantly reduce fall severity (Greenspan et al., 1994). Muscle mass, strength, and power decline with age, particularly in the lower extremities (Annianson et al., 1984) and this has been attributed, in part, to a decrease in physical activity. As a result, it is more difficult for the elderly to perform activities of daily living, particularly ambulation. Resistance training programs have demonstrated significant improvement in neuromuscular function in the elderly through the tenth decade, which translates to reduced risk of fall-related fractures.

"The foundation for bone health begins early in life. Physical activity that places a load on the bones is essential throughout childhood and the adolescent years."

<div align="right">Editors</div>

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