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OPTIMIZING BONE HEALTH: IMPACT OF NUTRITION, EXERCISE, AND HORMONES

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KEY POINTS

- Strong bones require a balanced "3-legged stool" of 1) regular physical activity, 2) adequate intake of calcium, and 3) normal hormonal levels.
- Osteoporotic fractures are preventable by maximizing "bone in the bank" by age 30 and by reducing rate of bone loss thereafter.
- Optimal exercise patterns for bone health include multiple brief bouts of activity accumulated over the day, focusing on weight-bearing activities that use a variety of movement directions.
- Adequate calcium intake is critical for achieving a high peak bone mass and slowing age-related bone loss, and may be essential for reaping the benefits of exercise.
- Hormonal changes can have a major impact on bone mass, outweighing exercise and nutrition effects.
- Too few Americans currently ingest enough calcium or exercise enough each week to optimize their bone health: This is a major public health challenge!

INTRODUCTION

Just 20 years ago, few athletic trainers, dietitians, and exercise physiologists were concerned with bone health, beyond the occasional fracture an athlete might incur. Relatively few exercise professionals worked with elderly, frail populations with diagnosed osteoporosis, which was often considered an inevitable consequence of advanced aging. Then, Dr. Barbara Drinkwater and colleagues (1984) caught our attention with their landmark publication documenting astoundingly low bone mineral density (BMD) values in young, competitive athletes who on average had not menstruated during the previous 3.5 years. The average BMD in the lumbar area of the spine in these otherwise healthy young women was equivalent to that of a 51-year-old woman. A burst of subsequent research in this area was aided by advances in the technology of BMD measurement and in pharmacological treatment of diagnosed osteoporosis, which together have transformed osteoporosis into a treatable, even preventable, disease.

Physical activity and calcium intake, are not the whole story, however. Robert Heaney of Creighton University has provided the apt analogy of the three-legged stool: Optimal bone health requires regular activity loading the skeleton, adequate calcium and Vitamin D intake, ***and*** normal levels of those hormones that impact on bone mass. The purpose of this brief review is to provide information critical to health professionals, athletes, and coaches about the best exercise for preventing osteoporosis, about how to include enough calcium in one's diet, and whether optimal diet and exercise habits can compensate for hormonal deficiencies.

RESEARCH REVIEW

Definitions

The key health risk of osteoporosis is acquiring a fragility fracture, that is, a bone fracture that occurs with very little trauma, such as with a fall to the floor. Unfortunately, this hallmark symptom of osteoporosis does not occur until bone loss has become quite severe. Clinicians have demonstrated that fracture risk increases 1.5 to 3-fold for each 10% drop in BMD below values typical to the young, healthy adult; hence, we use BMD as a surrogate measure of bone strength and resistance to fracture.

Bone mineral density (BMD) is simply that amount of bone mineral contained within a standard area of bone. ***Osteoporosis*** is defined clinically as a BMD value at any bone site that is less than the BMD of the lowest 2.5% of the population of gender-matched young adults. ***Osteopenia*** refers to BMD values that fall above osteoporotic values but within the lowest 16% of that same gender-matched young adult population. Clearly, if corrective actions are not pursued, osteopenia can develop into full-fledged osteoporosis. Even though we know that a good portion of bone mass consists of protein and other non-mineral substances, we typically use ***bone mass*** and ***BMD*** interchangeably; the mineral content of bone can be measured non-invasively, and BMD does correlate to a high degree with bone strength. The risk of developing osteoporosis can be minimized by two key strategies: 1) maximizing peak bone mass by age 30 and 2) slowing the rate of bone loss over the subsequent decades.

Exercise For Maximizing Peak Bone Mass

A key longitudinal study by Bailey et al. (1996) showed that up to 30% of peak bone mass is accrued in the three years surrounding puberty. Subsequent research confirmed the importance of regular activity (and optimal nutrition) over these years, as well as into adolescence. For example, Bailey et al. in 1999 verified that recreationally active boys and girls achieved 9% and 17% greater total body bone mineral content, respectively, as compared to inactive peers. Controlled exercise intervention trials provide the most stringent test of this relationship and generally confirm that, even in the prepubertal years, vigorous activity programs produce greater increments in bone mineral accrual than those observed in sedentary children (Bradney et al., 1998; Morris et al. 1997). It is noteworthy that those studies demonstrating the greatest impact of activity on bone mineral content or density in children or adolescents involve either a great diversity of recreational activity, high-impact activities (e.g., gymnastics, volleyball), or weight-bearing activities involving frequent, rapid changes of direction (e.g., tennis).

Whether the advantage of an active lifestyle during childhood is maintained through the young adult years or affects later fracture risk is not yet clear. What limited information we have to date suggests that this early advantage in higher peak bone mass may be lost by old age (Karlsson et al, 2000; Vuori, 2001). However, encouraging evidence does exist that a higher peak bone mass may be retained if physical activity is maintained, even at reduced levels (Kontulainen et al., 1999). The old adage “use it or lose it” appears to apply to skeletal adaptations just as it does to metabolic and cardiovascular changes with training.

Exercise For Adults Over 30: Slowing Bone Loss

Some studies on women between the ages of 30 and 55 support the widely held assumption that weight-bearing activities, both aerobic and strength-oriented, can stimulate a modest increase in BMD (Vuori, 2001). The gains in BMD in adult premenopausal women are much smaller (at best, 3% per year) than those observed in children and adolescents, and often require training periods of at least 12-18 months to develop. One unusual result was published by Rockwell et al. (1990), who demonstrated a ***decrease*** in lumbar spine BMD in 34- to 42-year-old women after nine months of circuit weight training. These women had high blood levels of parathyroid hormone, which tends to remove calcium from the bones. This suggests that calcium intake in these exercisers may have been insufficient despite ingestion of calcium supplements.

We still lack the definitive information to establish the minimum effective dose of exercise in postmenopausal women for slowing age-related bone loss or, ideally, stimulating an absolute gain in bone mass (Wallace & Cumming, 2000; Wolff et al., 1999). It is far more difficult to produce absolute gains in bone mass in older individuals, particularly in estrogen-deficient women. The most successful exercise interventions in postmenopausal women have utilized multiple forms of moderate- to high-intensity exercise in their regimens rather than relying on one mode of training only. By way of example, Dalsky et al. (1988) had their subjects perform a rigorous walk-jog program in combination with calisthenics and stair climbing and demonstrated a 5.4% increase in lumbar spine BMD after 9 months. In another study, Iwamoto et al. (1998) had postmenopausal women increase their daily walking distances by 45%, in addition to performing two sets per day of a calisthenics program that included straight leg raises, squatting, and strengthening exercises for the abdominal and back muscles. After 12 months, these subjects gained an average of 4.5% in lumbar spine BMD. Exercise-induced gains in BMD might be enhanced by as much as two-fold in those exercisers taking hormone replacement therapy (Kohrt et al., 1995).

In contrast to the positive results described above, many reports of exercise trials, well designed and assiduously supervised, have failed to show any absolute gain in bone mass in their dedicated exercisers, but instead, a halting of age-related bone loss. This latter result is still an important one: If bone mass can be stabilized and protected from further loss as we age, this is indeed a valuable achievement.

Some generalizations can be made about exercise programs for older women that appear to be the most effective for bone health:

- Exercises involving faster movements, as opposed to slow, static movements
- Exercise, be it resistance or aerobic in nature, that exceeds 70% of maximal capacity
- Movements that involve some impact, such as walking, jogging, or heel drops
- Programs involving a wide variety of muscle groups and movement direction.

One important caveat: For those individuals with severe osteoporosis, with or without fragility fractures, impact-producing exercise and those producing forward flexion of the spine should be avoided to minimize injuries (Bloomfield & Smith, in press 2001).

Role Of Calcium Intake And Interaction With Exercise

Although there exists some controversy about the relative importance of calcium intake versus weight-bearing exercise versus hormonal factors in optimizing bone health, there is no denying the evidence that individuals who consume low levels of calcium-rich foods have on average lower bone mass (and greater risk of fracture) than age-matched individuals who consume adequate or high levels of calcium. These findings have been documented in adolescent and young women (Anderson & Metz, 1993) as well as in older adult women (Heaney, 2000). Older individuals have, in fact, a double challenge: Just as their average energy needs and intakes are declining, the proportion of ingested calcium that is absorbed in the intestine declines. This in part explains why the recommended daily intakes for individuals over 50 years of age are higher than for younger individuals.

As reviewed by Cumming and Nevitt (1997) and by Heaney (2000), research shows an increase in bone mass and/or a reduction in risk of hip fracture with increased calcium intake, particularly in individuals with initially low dietary calcium. By way of example, a prospective 14-year trial found that calcium intakes over 765 mg/day were associated with a 60% reduction in risk of acquiring a hip fracture in men and women aged 50-76 years at the study’s outset (Holbrook et al., 1988).

Interestingly, there may be a threshold of calcium intake, perhaps 1000 mg/day, below which physical activity will have a minimal effect on increasing bone mass (Specker, 1996). If this is confirmed, there may be an increased calcium requirement in physically active people (Weaver, 2000). This hypothesized higher calcium requirement to support the increased bone formation presumably stimulated by physical activity, and the lack of response if higher levels of calcium are not available, would go a long way towards explaining apparent inconsistencies in the exercise and bone health literature. Examples of unusually successful exercise trials in terms of absolute gains in bone mass include those reported by Bloomfield et al. (1993), Dalsky et al. (1988), and Iwamoto et al. (1998). In each of these three studies, the postmenopausal subjects were consuming at least 1500 mg calcium per day as food and supplements. Accordingly, it appears that all active individuals should work diligently to meet the daily recommended intakes for calcium [1300 mg/d for adolescents, 1000 mg/d for adults 18-50 years, 1200 mg/d for adults over 50] to “cash in” on the bone-stimulating effects of their exercise regimens. With the increased availability of calcium-fortified foods and numerous calcium supplements to choose from, there are few excuses not to meet these intakes. [See the supplement to this article.]

The Last Leg: Hormonal Factors

Just as no stool can effectively balance on only two legs, optimal bone health requires a third factor beyond exercise and adequate calcium intake—normal levels of those hormones that affect bone formation and removal. In general, these hormonal effects are more powerful than those of physical activity and calcium intake. For example, elevations in circulating cortisol and other glucocorticoid hormones caused by medications required for chronic conditions such as asthma or inflammatory bowel disease can lead to significant bone loss over time, regardless of exercise or dietary calcium status (Lukert, 1999). Anyone regularly using any glucocorticoid, orally or by inhalation, should check with his or her physician about monitoring bone mineral density. Certainly it would be prudent to maintain regular physical activity and assure adequate intake of calcium; these measures should help minimize the adverse effects of the hormones.

Any suppression of circulating testosterone in men will also contribute to bone loss. Much of the age-related bone loss in aging men may be due to slowly declining testosterone production. Most people are aware that estrogen deficiency, commonly experienced at menopause but also with a prolonged absence of menstruation in some young female athletes, results in a rapid acceleration of bone loss in women. Declining estrogen levels may also play a major role in the slow, continuous phase of bone loss in aging men (Riggs et al., 1998). [Osteoporosis is not only a woman's disease; as many as one in four men now over 60 years of age will experience a fragility fracture in their remaining lifetime (Nguyen et al., 1996).]

The well-documented acceleration of bone loss in the first three to five years after the onset of estrogen deficiency, whether due to menopause or lack of regular menstrual periods in a younger woman, can result in as much as 3-5% loss of bone mass per year for this period. It has been known for several decades that hormone replacement therapy (HRT; usually a mix of estrogen and progestins) can effectively prevent this accelerated bone loss. Many women, however, are averse to long-term treatment with HRT or should not take it due to the risk of certain side effects (e.g., thrombus formation in those with a history of cardiovascular disease).

A common question many athletic trainers, personal trainers, and therapists are asked by women clients is whether regular vigorous exercise and adequate calcium intake can substitute for HRT. The simple answer is no, it cannot. Regular exercise may reduce some of the bone loss incurred with estrogen deficiency, but women who are not menstruating always have lower BMD values than estrogen-sufficient peers with the same exercise and nutritional habits. Regular weight-bearing exercise and high calcium intakes would be expected to attenuate but not prevent all of the bone loss driven by estrogen deficiency.

One cautionary note: There may exist an interaction between exercise and the use of oral contraceptives in healthy young women that results in a negative outcome for bone health. Two reports document a ***suppression*** of normal age-related increases in BMD in oral contraceptive users who completed a two-year exercise program (Burr et al., 2000; Weaver et al., 2001). If confirmed, these surprising effects have clear adverse implications for the attainment of peak bone mass in young women.

SUMMARY

Achieving optimal bone health and minimizing one's risk of osteoporotic fracture depends on two key strategies: accruing as much bone mass as possible over the first 30 years of life, and then slowing the rate of age-related bone loss thereafter. Exercise, adequate calcium intake, and minimizing hormonal changes that cause bone loss are the key tools we have to work with. Bone mass can be estimated by measuring bone mineral density, a commonly performed clinical test. Optimal exercise for bone health at all ages includes a diversity of movements using multiple muscle groups at moderately vigorous intensities. These activities should generate impact forces with weight bearing and emphasize faster over slower movements. Those with diagnosed osteoporosis can also benefit from regular physical activity but should avoid impact exercise and movements requiring forward flexion of the spine. Adequate calcium intakes are very important; active exercisers may require a minimum of 1000 mg calcium per day to reap the bone-stimulating benefits of their physical activity. Calcium from dairy food sources are absorbed the best, but many other options exist to include calcium in the diet as food or supplements. Glucocorticoid excess and estrogen deficiency at any age result in bone loss that cannot be fully compensated for by even vigorous activity and high calcium intakes.

The incidence of fragility fractures due to osteoporosis in developed countries is increasing at a rate even faster than can be accounted for by the increasing proportion of aged individuals in our population. This will have disastrous consequences in terms of health care costs (in the billions per year for the U.S. alone) and, more importantly, in deteriorating quality of life for those individuals unlucky enough to experience disabling fractures. Osteoporosis is a ***preventable*** condition; it is not an inevitable result of old age. Exercise and nutrition professionals can play a key role in reversing this trend if we are successful in persuading our clients and patients, and their children, to incorporate regular activity and higher calcium intakes into their daily routines.

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SUPPLEMENT

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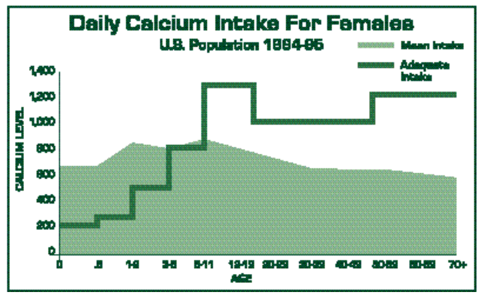
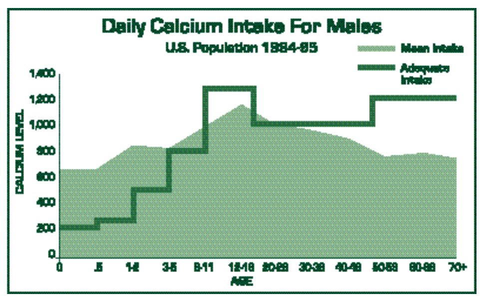
STEPS TO A STRONGER SKELETON

Exercise and dietary intake of calcium are two lifestyle factors within our control that can greatly improve bone health. The optimal characteristics of a physical activity program that typically will increase bone mass and thereby minimize fracture risk are summarized in the table below. Examples of physical activities that best "fit the bill" are weight-training (by machines or free weights), tennis, handball, racquetball, squash, gymnastics, volleyball, stair climbing, heavy gardening and lawn work, and step aerobics. The very best regimen would include at least three different activities spaced out over each week. Walking alone is likely to be effective only for previously sedentary individuals.

Characteristics of Bone-Building Exercise

- -Faster movements, as opposed to slow, static movements
- -Exceeds 70% of maximal capacity (70% of 1 RM, or 70% VO_2 max)
- -Involves some impact, such as stair climbing, jogging, heel drops
- -Involves a wide variety of muscle groups and movement direction





From Dairy Council of California web site www.dairycouncilofca.org

Achieving Adequate Calcium Intake

Over the last decade calcium requirements have been carefully redefined and reflect higher calcium intakes than the previous Recommended Daily Allowance values. The graphs to the right illustrate "Adequate Intake" values (in green) as compared to actual average intakes. Clearly, too many men over 50 years of age and girls/ women over 10 years of age are missing the mark by a wide margin. The latter group is highly unlikely to achieve its true biological potential in peak bone mass.

The general rule that vitamin and mineral dietary requirements are best met by eating foods rather than in supplement form is true for calcium as well. How much of the ingested calcium that actually gets absorbed in the intestine depends on many co-factors that are often present in food. The USDAFood Guide Pyramid recommends 2-3 servings of dairy products and 3-5 servings of vegetables per day. But there are many other sources as well, including calcium-fortified orange juice, which contains about the same amount of calcium (350 mg/cup) as skim milk. Additional food items containing calcium are listed in the accompanying table. Good news for caffeine-lovers: There is a lot of calcium in that caffe latte!

For those who need more calcium than they can eat and drink on an average day, there are many calcium supplements on the market that come in forms such as calcium carbonate, calcium citrate, and calcium lactate. Those individuals with impaired gastric acid production cannot absorb calcium carbonate well on an empty stomach, so they should take those supplements with a meal. Otherwise, absorption is best when calcium supplements are taken between meals.

(See Back)

RECOMMENDED WEBSITES

www.osteo.org Web page for NIH Osteoporosis and Related Bone Diseases National Resource Center, contains many links to other organizations including National Osteoporosis Foundation (www.nof.org)

www.dairycouncilofca.org Tremendous practical resource: estimate your own daily calcium intake, teaching aids and more.

http://text.nlm.nih.gov/nih/cdc/www/97.html Full text of Optimal Calcium Intake NIH Consensus Statement.

Calcium Content of Common Foods

Values provided by National Dairy Council

Plain, nonfat yogurt, 1 cup	452 mg
Swiss cheese, 1 1/2 oz	408 mg
American processed cheese, 2 oz	348 mg
Cheddar cheese, 1 1/2 oz	306 mg
Skim, nonfat, fat free milk, 1 cup	302 mg
2% reduced fat milk, 1 cup	297 mg
Chocolate milk, 1 cup	280 mg
Ice cream, 11% fat, 1/2 cup	88 mg
2% reduced fat cottage cheese	78 mg
Sardines with bones, 3 oz	371 mg
Canned salmon with bones, 3 oz	167 mg
Almonds, 1/2 cup	120 mg
Frozen cooked okra, 1/2 cup	88 mg
Frozen, cooked broccoli, 1/2 cup	47 mg
Orange, 1 medium	52 mg
Corn tortilla, 1, 6” diameter	42 mg
Cheese pizza, 1 slice, 1/2 of 15” diameter pie	220 mg
Caffe latte, 12 fl oz	412 mg
Cappuccino, 12 oz	262 mg

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