cient in the adolescent female, that low parental bone mass may lead to a daughter's low bone mass, and that such a low bone mass in the daughter could result in a future risk for osteoporosis. Also, in spite of the conflicting data in this area, the hypothesis of improving peak bone mass with increasing calcium intake remains tenable, and a 1,200 mg per day intake in adolescent females appears justified. Lastly, anorexia, and exercise-induced amenorrhea, will have extremely deleterious effects on bone.

Conclusions

In conclusion, this is a new and exciting area of osteoporosis research that at present has produced only preliminary data. As further studies on this subject are completed, the observation made by Dent (*12*) 15 years ago may be confirmed; that is, that senile osteoporosis is a pediatric disease.

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Panel Session: Nutrition/Exercise

The Role of Exercise in Preventing Osteoporosis

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Synopsis

Evidence from a variety of sources indicates that exercise can increase the mineral content of bone, raising the expectation that exercise programs may be effective therapy for the treatment of osteoporosis, and the prevention of hip and spinal fractures. Indeed, prospective studies demonstrate that primarily weight-bearing exercise prevents the age-related decline in axial skeletal mass and, in some instances, increases bone mineral content. Optimal changes in the skeleton in response to exercise are seen in those women with adequate intake of dietary calcium. Neither hormonal status nor age appears to preclude the skeletal benefits of exercise. The design of an exercise program must consider the physical condition of the participants, their current levels of activity, their compliance, and the objectives of the program. Generic programs that are not designed for individuals' needs and limitations, and that are not adequately supervised, will result in a high rate of musculoskeletal complications and noncompliance.

Unfortunately, additional studies are necessary before we can construct an optimum exercise prescription for bone health which addresses duration, frequency, intensity, and type of exercise. Of concern is the fact that gains in bone mass achieved with exercise are lost following their discontinuation in postmenopausal women, underscoring the concept that the level of physical activity is a major and

dynamic determinant of skeletal integrity. Thus, it will be necessary to develop strategies to preserve the gains in skeletal mass achieved through exercise. Finally, before exercise can be promoted for bone health, it will be necessary to demonstrate that such programs can indeed prevent osteoporotic fractures.

SKELETAL MATURATION CONTINUES long after linear bone growth ceases, so that peak bone mass is not achieved until the third decade of life. Skeletal involution during the fourth decade of life in women is accelerated by the loss of estrogens at menopause. Peak bone mass that is achieved during the third decade is considered a major determinant of the development of clinical osteoporosis later in life. Thus, osteoporosis may be as much a condition of childhood as of the older adult.

Prevention of osteoporosis depends on understanding those factors which determine the amount of bone mass achieved during the third decade of life: genetics, diet, hormones, and level of physical activity. Activity appears to be a determinant of peak bone mass, the subsequent maintenance of that bone mass, and skeletal integrity. Three types of data support this concept: (*a*) skeletal response to immobilization or hypogravity; (*b*) cross-sectional studies of bone mass in different populations; and (*c*) prospective or longitudinal studies of bone mass in response to exercise.

Immobilization and Hypogravity

The most dramatic demonstration of the interaction between activity and bone mass has come from studies of bed rest immobilization and the Sky Lab astronauts. Bone mineral loss of approximately 200 milligrams (mg) per day, or 0.5 percent of the skeleton per month, occurs with bed rest, with the majority of that loss apparently from the lower extremities (*1*). Consequently, calcaneal mineral losses are approximately 5 percent of the calcaneus each month, indicating that the responsiveness of various regions of the skeleton to disuse (lack of exercise) may be quite different, and dependent on their function.

Non-weight-bearing strategies designed to simulate the physical forces and hydrostatic pressures associated with walking are not effective in reversing negative calcium balances. Muscle activity with skeletal weight-bearing has proven effective in preventing bone mineral losses (*2*), whereas skeletal weight-bearing without muscle activity is ineffective (*3*).

The mechanical and biological control systems that mediate the maintenance of bone mass and structure have been the subject of intense investigation in recent years. Studies made with animal models and tissue culture preparations have confirmed the concept, advanced in the 19th century by Wolff, that bone is a dynamic tissue whose internal architecture and external confirmation are governed by the changing function of the bone, and resulting stresses. The nature of the signals that convert local stress or strain on bone to a biological response is unknown. Histological studies of bone from rats experiencing 19 days of hypogravity reveal an almost complete cessation of bone formation (*4*). Increases in urinary hydroxyproline and calcium excretion during immobilization and space flight (*1*) indicate that bone resorption is enhanced under these conditions.

Cross-Sectional Studies

Cross-sectional studies of the effect of habitual physical activity on bone status demonstrate, in general, a positive association between bone mass and activity (*5-10*). Lean body mass (total body potassium) and skeletal mass (total body calcium) maintain a constant ratio from 30 to 70 years of age (*11*) if adjusted for menopausal bone loss. This relationship is maintained in older adult marathon runners (*7*). Again, the implication is that the age-associated decline in muscle mass and bone mineral content need not occur and is, at least in part, due to disuse. All cross-sectional studies must be interpreted with caution because we have no way of excluding the bias that the level of physical fitness or activity is conditioned by, or directly related to, the skeletal mass. To evaluate an exercise effect, one must know the skeletal mineral content before initiation of the exercise. Concern about the effect of the bias is lessened by the observation that professional tennis players demonstrate marked hypertrophy of the humerus of the playing arm relative to the other arm (*6*).

The implications of cross-sectional studies are substantiated for the most part by longitudinal studies. Several studies have addressed the question of whether exercise can increase the bone mineral content of the postmenopausal woman. Simkin et al. (*12*) showed that a variety of loading exercises of the upper extremities could enhance the trabecular bone density of the distal radius over a 5-month period in women 53 to 74 years of age. A 3.8 percent increase in bone density was achieved with 15 minutes of bone-loading exercises three times a week. In an older and more sedentary population of women who were residents of a nursing home, Smith and Reddan (*13*) observed a 4.2 percent increase in the bone mineral content of the radius, compared with a 2.5 percent decline in a nonexercising control group. The exercise regimen was, by necessity, of low intensity three times a week for 3 years.

The response of the axial skeleton, specifically the lumbar spine, to various exercise programs has also been assessed, as reviewed in table 1. Only those studies (*14-17*) of sufficient duration and frequency of exercise to yield a significant difference between the control and exercise groups are included. The type of exercise prescribed varied, but was primarily weight-bearing of the lower extremities, including walking, jogging, and standing exercises. The study of Dalsky et al. (*17*) is the only one that specifically included stair climbing. The magnitude of the response compares favorably with reported medical regimens for the stimulation of net bone accretion, such as the use of fluoride, parathyroid hormone, calcitonin, or diphosphonates. The percentage of subjects completing the exercise programs ranged from 81 to 100. Three of 16 subjects dropped out of one exercise program because of musculoskeletal complaints that could be attributed to the exercise. Musculoskeletal complaints were also observed in the Dalsky et al. study, but did not prevent the participants' completion of the study. In that study, 76 percent of the women had an increase in bone density at 9 months, and 100 percent at 21 months. Thus, in terms of compliance, response rate, and adverse side effects, exercise appears to be an effective method of enhancing bone mass when compared with existing modalities of therapy. One caveat is that in none of these studies were the participants randomly selected. On the basis of other exercise studies, one can anticipate that compliance will be a major deterrent to the widespread application of exercise programs to the treatment of osteoporotic women.

Although these studies clearly demonstrate the potential efficacy of exercise in the treatment of clinical osteoporosis, they leave unresolved a number of important questions that need answers before we can formulate recommendations for the use of exercise in the treatment or prevention of osteoporosis. These include:

1. What is the appropriate exercise prescription for bone health (duration, frequency, intensity, and type of exercise)?
2. What are the roles of calcium, sex steroids, and age in the response to exercise?
3. Is exercise effective in the prevention of osteoporosis and fracture?

Type of Exercise

Considerable work has been done with animal models on the effect of exercise on the skeleton. From these studies, Canter (*18*) has developed a mathematical model relating bone maintenance to the intermittent mechanical stress imposed by daily activities or loading history. The results obtained using those models show that the magnitude of the loading stress is more important than the number of load cycles. Rubin and Lanyon (*19*) arrived at a similar conclusion, but added that diversity of the stress is also important in inducing the maximal increase in bone density. A number of studies in humans point to similar conclusions. Nilsson and Westlin (*20*) examined the bone density of the distal femur in professional and nonprofessional athletes, exercising controls, and sedentary controls. The rank order of femur density was weight lifters, throwers, runners, soccer players, swimmers, exercising controls, and sedentary controls. Again, the magnitude of the stress, not its frequency, seems to be important. Thus, weight-bearing should be an important component of an exercise program for bone health.

Aerobic exercises, designed to improve cardiovascular fitness, may not be beneficial. Furthermore, the exercise needs to be targeted to the part of the skeleton of concern. Weight-bearing exercises of the lower extremity may have little influence on the mineral content of the upper extremity (*16*). Exercise exerts a systemic effect on bone accretion (*21*), mediated perhaps by the release of somatotrophin. Additional studies are required to delineate this effect, and its potential for augmenting bone mass.

Perhaps the most significant observation of the Dalsky et al. study is that detraining results in a loss of bone mass to what is probably a new equilibrium between bone mass and the new level of exercise or physical activity. Those participants who returned to their previous level of activity returned to their baseline bone mass. These data are consistent with the close correlation between muscle mass and skeletal mineral content (*14*).

The effect of detraining on bone mass has significant implications for the use of exercise in the prevention of osteoporosis, for it suggests that gains in skeletal mineral content made earlier in life may not be sustained later in life. Wyshak et al. (*22*) compared the prevalence of bone fractures among former college athletes and their nonathletic cohorts in the menopausal and postmenopausal years. They found

Table 1. Longitudinal exercise studies of axial bone mass

Reference	*Group*	*Duration*	*Site*	*Response (percent)*
Sidney et al. *(14)*	High frequency high intensity	1 year	Total body	0
	Low frequency, low intensity			−9
Aloia et al. *(15)*	Exercise	1 year	Total body	+2.5
	Control	Aerobic		−2.4
Krolner et al. *(16)*	Exercise	9 months	Lumbar spine	+3.5
	Control			−2.7
Dalsky et al. *(17)*	Exercise	9 months	Lumbar spine	+4.9
	Control			−0.8
	Exercise	21 months	Lumbar spine	+6.1
	Control			−1.0

no difference between the two groups in the rate of any one type of fracture, or total fractures. Thus, to be effective in the prevention or treatment of osteoporosis, exercise may need to be continuous, or other strategies must be developed to sustain the gains in bone mass achieved through exercise. One such strategy in the post-menopausal woman that requires investigation is the use of estrogens.

The Role of Estrogens and Calcium

Hypogonadism in both men and women is associated with reduced bone mineral content (*23-27*). Exercise-induced amenorrhea in young women is associated with decreased bone mineral content (*25-27*). Recent studies have indicated that these women are frequently anorexic, and have low calcium intakes. In young women, both androgen and estrogen functions appear to be more important determinants of trabecular bone mass than aerobic exercise (*28*). In premenopausal women, a calcium intake greater than 750 mg significantly enhanced the increase in bone mass in response to exercise (*29*). There have been no studies which address the question of whether estrogens facilitate or impair the exercise-induced effect on bone mass, or whether their administration can cause retention of the gains in bone mass achieved by exercise.

There is sufficient evidence to suggest that exercise can increase bone mineral content at any age. The optimum effect of exercise on the skeleton requires an adequate intake of dietary calcium, as discussed in conference papers. Designers of exercise programs need to include such general considerations as the medical and physical condition of the participants, their current levels of activity, the objectives in terms of prevention versus treatment, and compliance.

One of the more important concepts in the effective prescription of exercise for any age group is to design the exercise program specifically for the individual. Generic programs are often ineffective or potentially dangerous because they cannot address the physical limitations or medical problems of the individual, particularly the older adult.

The intensity of the exercise depends on several factors, one of which is the objective of the exercise prescription. If the individual is not at increased risk of fracture, maintenance of the skeleton is probably achieved with a relatively low level of exercise, in contrast to the individual in whom prevention of additional fractures requires a significant increase in bone mass. The intensity is also dependent on the individual's medical condition, and habitual level of activity. An increase in the bone mineral content of the radius of the forearm bones of nursing home residents was achieved by Smith and Reddan (*13*) with a very low level of exercise, an intensity that would be inconsequential in younger, more active persons.

Another important consideration in the application of exercise to the treatment of an unselected population of osteoporotic women is compliance. Measures that have proven ineffective include: evaluating medical and physical limitations, designing a program to fit the individual's needs, providing adequate instruction and supervision, ensuring the use of proper shoes and clothing, and developing groups for peer support and socialization.

These general considerations help ensure developing a specific program for the individual, which addresses the frequency, duration, intensity, and mode of activity. In a sedentary postmenopausal population of women between 50 and 70 years of age, walking and stair climbing 3 to 4 times per week, 30 to 60 minutes per day, appears to be effective. Additional studies are required to determine the minimum or optimum regimen necessary to enhance skeletal strength.

Finally, in advocating exercise in the older adult, it is important to emphasize the other compelling reasons for participation. Exercise improves cardiovascular function, decreases carbohydrate intolerance, improves serum lipid profile, improves mental function and reaction time, and decreases the liability of falling. The last effect is conjectural, but may be a more important determinant of reducing fractures than an increase in bone mass. Therefore, designing exercise programs for older osteopenic women should address improvement of gait and stability, as well as increases in bone strength.

Weight-bearing exercise has excellent potential for the treatment of osteoporosis and the prevention of fractures. Additional studies are needed to ascertain (*a*) the types of exercise best suited to achieve improved skeletal integrity, particularly in the proximal femur and spine; (*b*) the conditions, such as age and hormonal status, that will facilitate the skeletal response to exercise; and (*c*) whether exercise regimens can effectively prevent fracture, specifically hip fracture.

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