JOURNAL OF BONE AND MINERAL RESEARCH
Volume 16, Number 2, 2001

Editorial

Exercise Maintains Bone Mass, but Do People Maintain Exercise?

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INTRODUCTION

IT HAS long been recognized that increased mechanical loading of the skeleton results in bone gain, whereas unloading the skeleton leads to bone loss. This relationship between loading and bone is implicit in the writings of Julius Wolff,[(1)] who proposed that bone structure, including the distribution and amount of mineral, reflect the customary loading patterns that the bone is subjected to. It follows that an increase in weight-bearing physical activity would increase bone mass and present a seemingly simple preventative strategy for prevention and treatment of osteoporosis. This seemingly simple strategy has proven difficult to achieve in practice, because most exercise interventions in adults have led to increases in bone mass that are relatively small.[(2–5)] However, even if the ideal bone-promoting exercise regimen was known, one would still be faced with the tremendous challenge of motivating individuals to exercise for their health, whether skeletal or otherwise.

In this issue of the Journal, the article by Kontulainen et al.[(6)] offers some hope for the maintenance of bone gained through intensive exercise training, even when the level of training is subsequently reduced. The subjects in this observational study initially self-selected to participate in rigorous racquet sports (tennis or squash) for an average of four to five times per week. The authors previously reported that those women who started training before menarche had a greater skeletal benefit, assessed as the difference in bone mineral content (BMC) between the playing and nonplaying arm, than those who started after menarche.[(7)] During the 5-year follow-up period, the subjects voluntarily reduced their playing time to just once or twice each week. Results from the current study suggest that both "young starters" and "old starters" maintained this skeletal benefit despite a reduced training schedule. After the reduction in training, the difference in BMC of the nondominant versus dominant humeral shaft was 22% in the young starters, 10% in the old starters, and 3.5% in control subjects. Although this is good news for the athletically inclined members of our society, the critical issue is whether controlled interventions will result in similar benefits and, ultimately, translate to a reduction in the risk of osteoporosis and related fractures.

To understand the relationships more thoroughly among mechanical loading, growth, and bone it is essential to distinguish between effects on bone size and bone density. Kontulainen and colleagues represent skeletal benefit in terms of side-to-side differences in humeral BMC. This limits the possible interpretations of their findings, because BMC measurements reflect both bone size as well as bone density. Before skeletal maturity, the effects of exercise on the skeleton may be mediated primarily by alterations in bone size and shape.[(8)] Apparent skeletal benefits resulting from alterations in skeletal geometry may be more resistant to subsequent reductions in mechanical loading than skeletal benefits solely because of increased bone density.

The precise relationships between skeletal loading, in the form of exercise and skeletal status have yet to be defined. Studies of the effects of physical activity on bone vary with respect to the exercise regimen used, skeletal site assessed, study population enrolled, and bone densitometry technique used. As such, it is difficult to generalize about the public health benefits of exercise interventions for the prevention of osteoporosis, although there is general agreement that weight-bearing exercise confers a positive effect on the skeleton. Growing evidence indicates that impact loading may provide the greatest osteogenic stimulus for the skeleton.[(9–11)] However, despite the potentially positive effects of impact loading on bone mass and density, some

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have argued that impact loading may lead to increased risk of osteoarthritis, thereby suggesting that "what is good for the bones may be bad for the joints."[12] In the study by Kontulainen and colleagues,[6] the loading regime associated with racquet sports is likely to include impact-type loading. As such, it may not be possible to apply the conclusions from this study with regard to the maintenance of exercise-induced bone gain to alternative exercise programs that do not involve impact loading.

It remains to be seen whether controlled interventions or exercise regimes with different loading characteristics will result in similar benefits. For example, in contrast with the Kontulainen study, Dalsky et al. found that in postmenopausal women bone mass returned to baseline levels after cessation of exercise.[13] In addition, cross-sectional studies of former athletes suggest that skeletal benefits, either in terms of increased bone mineral density (BMD) or reduced fracture incidence, are not maintained after cessation of training,[14] except possibly in the case of athletes subjected to impact-type loading before puberty.[15] There are several possible explanations for the discrepancies between these studies. For example, it is possible that the self-selected trainees are an elite group whose skeletal status (and muscle mass and overall health) is already above the norm, making it possible to gain and sustain an increased bone mass with a period of intensive training followed by moderate exercise thereafter. Their self-selected diets and other lifestyle habits may contribute to their success. Moreover, they may be a group who have been interested in physical activity since childhood, and therefore they may have been more active all of their lives. As mentioned before, it is likely that individuals who begin intensive training before puberty enjoy a greater effect on bone size and mineral density than those who start later in life. Finally, it may be that the once or twice weekly, impact loading associated with racquet sports provides sufficient osteogenic stimulus to maintain the skeletal benefit.

Critical evaluations of exercise intervention programs must include some discussion of problems with compliance to the prescribed exercise regimen. Not surprisingly, it appears that better compliance with an exercise intervention is associated with younger subjects and shorter-term programs. In a 3-year controlled randomized trial of weight-bearing exercise on BMD in healthy premenopausal women, Sinaki et al. reported a dropout rate of 34% in the exercise groups and 22% in the controls.[16] In a 2-year trial of brisk walking in postmenopausal women there was 41% attrition in both arms of the study.[17] However, in the same age group, the reported compliance was much better in a short-term study, ranging from 72% to 80%.[18] In a long-term study of elderly women, after 7.7 years, the compliance rate for an in-home exercise program was only 36%.[19]

These observations are more relevant to the real world of osteoporosis prevention than are the observations of physically active people who are not only self-motivated but are interested in intense participation in a particular sport. Several older studies identify other determinants of motivation and retention in exercise studies, including the physical condition of the participants, their current levels of activity, and various psychological and socioeconomic characteristics.[20] By logical extension, other relevant factors include body size, previous activity levels, concern about health, access to resources, and so on. Birge and Dalsky[21] concluded that generic programs, ones that are not tailored to individuals' needs and circumstances, are unlikely to be very successful. From a public health standpoint, this is discouraging, because it is virtually impossible to develop individualized programs on a broad scale for prevention of any disease, including osteoporosis.

A critical question to ask in terms of exercise and skeletal integrity is whether exercise either during growth or throughout life will have a beneficial effect on bone in later life, and, more importantly, will ultimately reduce fracture risk. To date there are no randomized trials showing that exercise intervention reduces fracture risk. Moreover, it is unlikely that such a study will be undertaken because of the large number of subjects and extended follow-up period that would be required. Therefore, one can only hypothesize about the mechanisms by which exercise either in adolescence or adulthood or both, may influence fracture risk. First, it is clear that exercise during the period of skeletal acquisition may allow an individual to achieve their optimal, albeit genetically constrained, peak bone mass—thereby putting more bone in the bank to offset the inevitable withdrawals later in life. Henderson and colleagues suggest that the effect of a 7–8% increase in peak BMD, if maintained throughout the adult years, could translate to a 1.5-fold reduction in fracture risk.[22] Although plausible, it remains to be proven that a higher-peak bone mass will indeed reduce fracture incidence some fifty years later. Second, exercise may attenuate bone loss in later years,[23] but, perhaps most importantly, exercise may reduce the frequency and severity of falls. Although multifaceted intervention programs may be most effective in reducing falls in older adults,[24] exercises targeted at improving balance and strength have proven effective at reducing falls in the elderly.[25] Furthermore, various exercise interventions have proven effective at improving neuromotor skills associated with increased risk of falling.[26,27] The strongest evidence that among the elderly the positive effects of exercise on fracture risk may be mediated by reducing falls is that walking, which has minimal effects on BMD, is associated with a reduced risk of hip fracture.[28,29]

A less well-understood factor in the efficacy of exercise in preventing osteoporosis is the impact of genetics, which influence peak bone mass as well as other aspects of skeletal health. At least one paper has suggested a role for genetic polymorphisms in the response of bone to exercise intervention.[30] Tsuritani et al. found that the "*bb* " genotype of the vitamin D receptor (VDR) gene may confer greater responsiveness of bone to exercise than the other VDR genotypes.[30] However, Jarvinen et al. did not find an effect of the VDR genotype on the osteogenic response.[31] Recently, a study of a myostatin-deficient mouse model found that despite vastly increased muscle mass, the femora of these mice were not abnormal in size or shape.[32] This finding suggests that the bone did not adapt to the increased muscle mass as would be expected from Wolff's law, perhaps because these mice have more (genetically deter-

mined) muscle than is needed for normal activities affecting the skeleton.[33] Thus, as Turner points out in an accompanying editorial, the "genetics have superceded the biomechanical balance between muscle and bone."[33] These fascinating data should stimulate further research in this area, and a better understanding of the interactions of genes and the environment in relation to skeletal health can only improve our ability to devise appropriate public health measures for the prevention of osteoporosis.

In view of the previous cursory discussion of the many factors that can affect the skeletal benefits of exercise and despite the hopefulness of the study by Kontulainen et al. in this issue of the Journal,[6] the relative utility of exercise intervention in maintaining or increasing bone mass in the general population is still problematic. For those individuals who are willing and able to be active and stay active, at least moderately, there appear to be multiple benefits of exercise in overall fitness, balance, and strength. The importance of these benefits for preventing falls that might result in fracture cannot be emphasized enough. The greatest effects of physical activity on bone mass appear to occur during growth and development. Therefore, it seems reasonable to turn our attention to intervening in the younger population in hopes of establishing lifelong exercise habits that maximize peak bone mass within the limits of one's genetic potential. In addition, this lifelong exercise may ultimately reduce fracture risk by attenuating age-related bone loss and lowering the incidence and severity of falls. Motivating people, at any age, to get involved and to stay involved in physical activities for their skeletal health is the ultimate challenge.

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