REVIEW

Osteoporosis and exercise

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Osteoporosis is a common medical problem. Lifestyle measures to prevent or help treat existing osteoporosis often only receive lip service. The evidence for the role of exercise in the prevention and treatment of osteoporosis is reviewed.

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The association between mechanical stress and bone mass was first recorded by Galileo in 1683 who noted the relationship between body weight and bone size; but it was not until 1892 that Julius Wolff, a German anatomist realised that changes in the mechanical stresses applied to a bone influenced bone strength.[1] Immobility or prolonged bed rest rapidly leads to hypercalcuria, negative calcium balance, and bone loss.[2] However in paralysed individuals, weightbearing without muscle activity—for example, assisted standing—does not decrease the urinary calcium losses or affect the bone mass. From these findings, it would seem the duration and force of the muscle activity on bone are important in maintaining bone mass.[3] The aim of this paper is to review the evidence for exercise preventing and treating osteoporosis, with the protective effects against fracture also considered.

CROSS SECTIONAL STUDIES OF EXERCISE AND BONE DENSITY

Many cross sectional studies have been performed to investigate the effect of exercise and activity on bone mass.[4–6] Most studies have demonstrated a positive correlation between exercise levels and bone mass. However cross sectional studies demonstrate simply an association, and do not imply causation. Furthermore, the association is based on lifetime exercise and does not mean that exercise in previous sedentary individuals can prevent or reverse osteoporosis.

(1) Population studies

Observational studies assessing physical activity by questionnaire have demonstrated an association between bone density, childhood physical activity,[7] current physical activity,[8] and lifetime physical activity.[9] Childhood physical activity level was significantly related to calcaneal bone mineral density (BMD) in 101 young women, but in the same study, the association with current activity level did not reach statistical significance.[7] Krall and Dawson-Hughes using a validated questionnaire, studied participation in outdoor walking and other leisure time physical activity in 239 postmenopausal women. They found significantly increased whole body, leg, and trunk BMD in women who walked more than 7.5 miles per week compared with women who walked less than one mile per week. In this study, current walking activity reflected lifelong walking habit.[9] A similar association between BMD and physical activity was reported in the lumbar spine of postmenopausal women.[10] BMD correlated significantly with back muscle strength and level of current physical activity. A physically active occupation has also been shown to be important. Lifelong manual labour in men is associated with reduced rates of bone loss from the metacarpal when compared with men in sedentary occupations.[11] Two groups have used objective methods to measure current physical activity. Aloia and colleagues assessed current physical activity in 24 premenopausal women using a motion sensor and found a significant independent association with BMD at the spine, but not at the radius.[12] However other workers using a pedometer in premenopausal women failed to demonstrate an association between current physical activity and BMD at any of the four measured sites.[13]

Pocock and co-workers were the first to demonstrate a correlation between physical fitness (and by implication habitual physical activity) and bone mass.[14] They objectively studied physical fitness in 84 healthy premenopausal and postmenopausal women aged 20 to 75 years using predicted maximal oxygen uptake (Vo_2 max) during a submaximal bicycle ergometer test. They found Vo_2 max to be significantly associated with BMD at both the femoral neck and spine, but not at the radius. In the 46 postmenopausal women, physical fitness was the only significant predictor of femoral BMD. More impressive evidence for an association between physical activity and BMD results from the consistent association between muscle strength and BMD. Hand grip strength has been shown to be positively associated with BMD at the radius in postmenopausal women,[15] and a similar relationship has been described between lumbar spine BMD and back strength.[10]

(2) Athletes *v* sedentary controls

Further support for an osteogenic effect of exercise has come from studies comparing the BMD of recreational or elite athletes in a variety of different sports with sedentary controls.[4 5] Numerous studies have shown higher bone density measurements in recreational or competitive runners. In a study of male and female athletes over 50 years old who had been long distance running for an average of nearly nine years, lumbar bone mass was higher in women and men

Abbreviations: BMD, bone mineral density; Vo_2 max, maximal oxygen uptake compared with sedentary controls.[16] A similar effect has been reported in male cross country runners when compared with age matched sedentary controls.[17] Runners who had all been practising the sport for at least 25 years had significantly increased bone mass in the calcaneus, femoral shaft, head of humerus, and distal forearm bones. Weight or strength training is associated with significantly increased BMD in athletes. Competitive weightlifters have significantly increased lumbar spine BMD compared with sedentary age matched controls.[18] Similarly, increased BMD was reported at the spine of young women who took part in muscle building activities compared with individuals whose physical activity was predominantly aerobic.[19]

Other weightbearing sports are also associated with increased BMD. In a study of female college athletes and sedentary controls, BMD measured at the calcaneus and lumbar spine was highest in volleyball and basketball players and was significantly higher than sedentary controls.[20] In this study, the BMD of swimmers was no different to the BMD of sedentary women. Similarly Heinonen and colleagues in Finland compared BMD in female squash players, aerobic dancers, and speed skaters with controls.[21] Squash players, speed skaters, and dancers had significantly increased BMD compared with the control group, with differences in BMD parallelled by differences in isometric muscle strength. Similar results have been described in young men where spinal mineral density assessed by computed tomography was 14% greater in active compared with sedentary men. Analysis of variance showed significant differences in bone density based on type of exercise, with greatest bone density seen in men taking aerobic and weightbearing exercise.[22] It is of note that two studies have shown that BMD is maintained in older subjects in the medium term (5–7 years); these subjects previously had an intensive exercise regimen but adopted a less intensive regimen.[23 24]

(3) Unilateral limb studies

The effect of unilateral activity on one limb of an individual has been studied and compared with the "non-exercising" limb. This study design has the advantage of controlling for all other genetic and environmental influences. These studies show a marked effect of exercise.[5] In a study of female squash players from Finland, BMD at the proximal humerus of the racquet hand was 15.6% higher than the inactive arm and was significantly related to the number of training years.[25]

INTERVENTION STUDIES

Although numerous intervention studies have been performed, many are poorly designed with no proper randomisation and inadequate sample size. However we will review mainly randomised controlled trials and only include other studies where randomised trials are lacking.

In a two year randomised controlled trial 127 women aged 20–35 years were allocated to either a high impact aerobic exercise training programme, or to maintain their current activity levels or participate in a programme of light stretching.[26] Only 63 women completed the study (31 controls) but those in the exercise group significantly increased their BMD at the spine, femoral neck, greater trochanter, and calcaneus compared with the control group. Similar beneficial effects have been reported in a small randomised controlled trial of jogging and weight training for eight months. BMD measured at the hip and spine increased in joggers (1.3%) and weightlifters (1.2%) compared with controls, but the increase at the hip did not reach statistical significance.[27] Similar site specific increases have been reported in young male rowers. In a controlled study of 17 novice rowers, spine BMD increased by 2.9% after seven months of training.[28]

Chow and colleagues randomised 48 healthy postmenopausal women to a control group, aerobic exercise group, or a strength training group for one year.[29] Compliance at the exercise classes was 70% and at the end of the programme both exercise groups had significantly greater bone mass than controls. However, there was no significant difference between the aerobic and strength trained groups. In an elegant study of 56 postmenopausal women, subjects were randomised to either high repetition, low load (endurance) or high load and low repetition (strength) training groups for one year.[30] Significant gains in BMD compared with the control limb were seen at the hip and radius in the strength group, but only at the radius in the endurance group. It seems likely that peak load rather than number of repetitions is the more important factor in achieving bone gain.

Nelson and co-workers studied the effect of a high intensity strength training programme on femoral and lumbar BMD.[31] Significant increases were seen at both sites in the exercise group, with a fall in BMD seen in the control group. The differences in BMD were independent of change in diet and significant changes also occurred in muscle mass and strength. Similar findings were reported by Lohman and colleagues from a programme of weightlifting in premenopausal women.[32] They found a significant increase in lumbar spine BMD after 18 months (3%–6%), noting that the major change in BMD took place after the first five months of exercise (2.8%). High intensity strength training can significantly increase BMD.

High impact exercise of increasing intensity in healthy premenopausal women leads to significant increases in hip BMD compared with controls.[33] A significant increase of 1.6% in femoral neck BMD was seen in the exercise group compared with a reduction in BMD in controls (−0.6%) The effect was site specific and there were no differences at non-weightbearing sites. Bassey and Ramsdale report a similar effect in premenopausal women after six months of high impact (jumping and skipping) activity compared with controls whose exercise was low impact only.[34] Using a crossover study design, they demonstrated a similar increase in the control group in response to high impact activity. Strength training with non-weightbearing exercises does not appear to lead to an increase in BMD.[35 36]

Regular brisk walking can maintain BMD in previously sedentary postmenopausal women. In a prospective randomised controlled trial over 12 months, BMD at the spine and calcaneum decreased in the control group but small increases were seen in the walking group with the differences reaching statistical significance at the calcaneum.[37] There has been one randomised controlled trial of a "home based" exercise programme in postmenopausal women.[38] Women in the exercise group were asked to flex each hip 60 times two or three times each day with a 5 kg bag on the knee and changes in BMD were measured at the lumbar spine. On an intention to treat basis there was no significant benefit from exercise. However, on subgroup analysis subjects who exercised assiduously lost significantly less bone than controls.

Most intervention studies have attempted to increase BMD at specific sites by careful targeting of the exercise. Only one randomised study has demonstrated any significant systemic effects of exercise on bone density.[15] In postmenopausal women there was a significant difference in the cross sectional area of the radius after a three year walking programme, although loss of BMD was similar in both groups.

ESTABLISHED OSTEOPOROSIS

A number of studies have demonstrated significant gains in BMD in individuals with osteoporosis. In an open study of postmenopausal women with a fractured forearm, patients were asked to squeeze a tennis ball three times a day for six weeks using their uninjured arm.[39] Muscle strength improved

Box 1: Example of exercises involved in home based low impact exercise programme[45]

(1) Five minute warm-up consisting of general whole body pulse raising and mobility promoting activities, followed by preparatory stretching of the main muscles being worked in the core programme.
(2) Core programme of low impact exercises:
- Box step
- Heel presses
- Step-step-kick-step-step-back
- Upper body twists
- Cross steps
- Knee lift triangles
- Stomach exercise-shoulder lifting off floor while on back
- Rowing action
- Bent side leg raise
- Bent leg raise
- Front leg tucks
- Side leg presses

(3) Five minute period of pulse lowering activity and stretching.

Notes:
(i) Exercise regimen needs to be taught by suitably qualified professionals.
(ii) Regular face to face contact with supervising professional required.
(iii) Level of intensity at start depends on capabilities of individual.
(iv) Intensity of exercise increased by increasing the number of repetitions and increasing resistance to movement.
(v) Exercise regimen needs to be undertaken at least twice per week.

significantly and bone mineral content also increased significantly as a result of exercise. Significant improvements in bone mass can also occur as a result of low impact exercise at the lumbar spine of women referred with established osteoporosis.[40] Similar benefits have been reported in women with low BMD who have taken part in strength training.[41 42] Iwamoto *et al* in a randomised controlled trial also found that high impact exercise increased BMD. However continued exercise was required to maintain any gains.[43]

There are two randomised controlled trial of exercise in corticosteroid induced osteoporosis. In the first, 16 male heart transplant recipients after transplantation were randomised to strength training or control groups. However after six months of exercise, BMD in the exercise group had increased significantly towards pretransplant levels but BMD in controls remained unchanged from values two months after transplant.[44] In the other trial, low impact training in patients with Crohn's disease who were compliant with the programme, lead to an increase in BMD at the hip (see box 1).[45]

OPTIMUM TYPE AND FREQUENCY OF EXERCISE

The duration, intensity, frequency, and optimum type of physical activity for increasing BMD and reducing fracture risk has not been determined. However, invasive studies of controlled local loading in animal models suggest that the effective osteogenic forces are at the top end of the range normally experienced, are rapid in onset, and unusual in their strain pattern.[46] Population studies involving athletes indicate that high impact sports such as running, squash, and weightlifting lead to an increase in BMD, whereas low impact sports such as swimming do not.[18–22] Intervention studies also suggest that high impact activities are better at increasing BMD than low impact activities. Low impact activities only seem to help prevent further loss.[26 27 34] Other reviewers have concurred with this view.[47]

Compliance with exercise regimens is a very important factor in trying to increase BMD and changing sedentary lifestyles is very difficult.[38] Three intervention studies have successfully shown that previously sedentary individuals could increase their activity levels. They shared a number of features—(i) home based, (ii) unsupervised informal sessions, (iii) frequent professional contact, (iv) walking as the promoted exercise, and (v) exercise of moderate intensity and lesser frequency—that were associated with higher participation. Continued exercise is also important in maintaining previous gains in BMD, otherwise bone loss recurs and previous gains are lost.

No intervention study has assessed the effect of exercise on the rate of osteoporotic fracture. The evidence for exercise having a protective role against hip fracture comes from large epidemiological studies. Paganini-Hill and colleagues, in a study from the USA, reported an odds ratio of 0.3 for hip fracture in women who had a high frequency of participation in outdoor sports, compared with those with a low frequency of participation.[48] A similar risk reduction has been reported in studies from Britain[49] and Hong Kong.[50] Cooper and colleagues in the UK found a significantly reduced risk of hip fracture in individuals who were physically active for more than five hours a week.[49] Kujala *et al* in Finland found that vigorous exercise provided a similar protective effect for osteoporotic hip fracture.[51]

CONCLUSION

Cross sectional studies have shown a positive correlation between bone mineral density (BMD) and exercise. Intervention studies suggest that high impact exercises are better at increasing BMD (table 1). The effect is site specific. Uptake and continued compliance is crucial to any intervention in the form of exercise on BMD. It is the opinion of the authors that exercise should be encouraged in those at risk of osteoporosis and those with osteoporosis, along with other life style measures (adequate calcium intake, stopping smoking, modest alcohol consumption, and maintaining an adequate body weight). Exercise has important additional benefits, such as increased

Table 1 Different forms of exercise and their impact on BMD

Form of exercise	Impact on BMD	Sites	Study
Swimming	None	—	20
Walking	Protects against further loss	Hip, lumbar spine	37
Gentle aerobic exercise (low impact)	Protects against further loss, may increase	Hip, lumbar spine	26, 27, 34, 40, 41, 42, 45
Vigorous aerobic exercise (high impact)	Increases	Hip, lumbar spine	21, 26, 27, 29, 33, 34
Weight training	Increases	Hip, lumbar spine, radius	18, 19, 27, 29, 30, 31, 32,
Running	Increases	Hip, lumbar spine	16, 17
Squash	Increases	Hip, lumbar spine, racquet hand	21

muscle strength and coordination, which decrease the risk of trauma leading to osteoporotic fractures. Exercise also has other benefits, which are important for the general wellbeing of patients—for example, decreasing cardiovascular disease, decreasing the risk of diabetes, and helping depression.

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