Osteoporosis and exercise

J A Todd, R J Robinson

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.

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. Immobility or prolonged bed rest rapidly leads to hypercalcuria, negative calcium balance, and bone loss. 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. 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. 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, current physical activity, and lifetime physical activity. 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. 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 less than one mile per week. In this study, current walking activity reflected lifelong walking habit. A similar association between BMD and physical activity was reported in the lumbar spine of postmenopausal women. BMD correlated significantly with back muscle strength and level of current physical activity. A physically active occupation has also been shown to be important. Lifetime manual labour in men is associated with reduced rates of bone loss from the metacarpal when compared with men in sedentary occupations. 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. 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.

Pocock and co-workers were the first to demonstrate a correlation between physical fitness (and by implication habitual physical activity) and bone mass. They objectively studied physical fitness in 84 healthy premenopausal and postmenopausal women aged 20 to 75 years using predicted maximal oxygen uptake (Vo2 max) during a submaximal bicycle ergometer test. They found Vo2 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, and a similar relationship has been described between lumbar spine BMD and back strength.

(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. 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; Vo2 max, maximal oxygen uptake |

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compared with sedentary controls. A similar effect has been reported in male cross country runners when compared with age matched sedentary controls. 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. 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.

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. 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. Squash players, speed skaters, and dancers had significantly increased BMD compared with the control group, with differences in BMD paralleled 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. 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.

(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. 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.

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 programme in postmenopausal women. In a prospective randomised study there has been no demonstration of a significant increase in the calcaneus BMD of swimmers compared with controls. 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. 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. Muscle strength improved
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. Similar benefits have been reported in women with low BMD who have taken part in strength training. 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.

There are two randomised controlled trials 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. 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).

### 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. 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. 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. Other reviewers have concurred with this view.

Compliance with exercise regimens is a very important factor in trying to increase BMD and changing sedentary lifestyles is very difficult. 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. A similar risk reduction has been reported in studies from Britain and Hong Kong. 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. Kujala et al in Finland found that vigorous exercise provided a similar protective effect for osteoporotic hip fracture.

### 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 lifestyle 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

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