

Bone density and physical activity

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Osteoporosis is currently the major cause of fracture in older people. The most common fractures in the UK are hip fractures (60 000 per year), closely followed by wrist (or Colle's) fractures (50 000 per year) and vertebral fractures (40 000 per year). Many osteoporotic fractures are associated with significant morbidity and mortality, with hip fractures being the most severe consequence. Of hip-fracture victims, 5–20 % will die within 1 year of the fracture and many more experience long-term disability which seriously reduces the quality of life. In 1994 the cost to the National Health Service was approximately £750 million, and with the growing elderly population this figure is set to rise.

The maximal load a bone can withstand without fracture is positively related to its bone mineral density (BMD). Bone mass peaks between the ages of 20 and 40 years, with men achieving a greater peak bone mass. After the age of 40 years, bone mass declines at a rate of 0.5–1.0 % per year, with an accelerated period of loss in women for 5–10 years after the menopause. In total, women lose about 25–30 % of the cortical bone and 35–50 % of the trabecular bone over a lifetime; men lose at about two-thirds this rate (Riggs *et al.* 1981). This leaves thin cortical bone and thin or interrupted trabecular plates. Once bone mass has declined to a critical threshold, fractures are likely to occur. Physical activity is one of the factors which can influence the attainment of peak bone mass and reduce the age-related loss. For this reason, there is considerable interest in identifying the most effective forms of exercise for increasing BMD with the assumption that, in the longer term, this will reduce fracture incidence. A large number of intervention and cross-sectional studies have been conducted to try and identify the optimal form of activity for improving bone density. The present review aims to highlight those studies which have provided evidence that activity is good for bone and point to those forms of exercise which have been shown to improve BMD at the key fracture sites. In addition, attention will be drawn to possible detrimental effects of exercise on BMD and fracture incidence.

FALLS AND FRACTURES

The majority of osteoporotic fractures, particularly those of the hip, occur as a result of a fall. It is important, therefore, to consider the factors which predispose the person to fall. These risk factors include: psychoactive drugs and other medications; dementia, depression and cognitive function; poor proprioception; poor gait and muscle strength; poor postural stability; dizziness and vestibular problems; poor functional ability; poor eyesight. Of these, muscle strength, postural stability and functional ability may be improved by the appropriate exercise. In the older person, therefore, exercise regimens should be designed to target these risk factors in addition to improving BMD.

IMMOBILIZATION AND WEIGHTLESSNESS

Evidence that physical activity, or bone loading, is important in maintaining or improving bone density comes from situations where the loading is reduced. In human subjects the studies have largely taken two forms: bed rest and space travel.

Space flight is the closest we get to completely eradicating mechanical and gravitational forces. With the potential for longer flights, preventing significant bone loss is one of the priorities of the space agencies. Early studies on the Apollo and Skylab space flights demonstrated that there is an increased Ca excretion similar to that observed during bed rest (see later). Large decreases in calcaneal bone mineral content occur during microgravity with bones of the upper limbs being spared (Vogel & Whittle, 1976). This is probably due to the increased use of the upper limbs required to manoeuvre between shuttle compartments and perform tasks.

Bed rest causes an increase in Ca excretion and bone mineral loss in the weight-bearing bones such as the calcaneus, iliac crest and lumbar spine (Whedon, 1984). In a study of patients undergoing therapeutic bed rest because of backache, Krolner & Toft (1983) found an average loss of lumbar-spine bone mineral content (BMC) of 0.9% per week. On re-ambulation BMC recovered, but the rate of recovery was much slower than the rate of loss. Strict bed rest in healthy, young male volunteers produced significant reductions in BMD from the lumbar spine (-4%), femoral neck (-4%), tibia (-2%) and calcaneus (-10%) over 4 months (LeBlanc *et al.* 1990). Attempts have been made to counter bone loss during bed rest by induced mechanical stress. Sitting and exercising supine on a cycle ergometer did not decrease Ca excretion in young men exposed to bed rest. However, quiet standing for 3 h daily did prevent the change in mineral metabolism (Issekutz *et al.* 1966). Whether shorter periods of standing would be equally effective is unknown.

Clearly these findings have many practical implications for the medical care and rehabilitation of patients at risk of fractures or who have sustained a fracture and consequently may require immobilization or bed rest. Bed rest could exacerbate existing osteoporosis or cause bone density to cross the fracture threshold in an elderly patient. Early weight-bearing is essential and, as bed-rest is also accompanied by muscle loss, care should be taken in the remobilization period to reduce the chance of falls and fracture.

CROSS-SECTIONAL STUDIES

There have been a myriad of studies investigating the bone density of different athletic groups and matched sedentary controls. In general, results show differences (6–20%) in BMD and BMC between exercisers and controls at different anatomical sites, over a wide range of physical activities. Nilsson & Westlin (1971) measured bone density in the distal femur in a variety of male athletic groups ranked by the load taken on the lower limb, i. e. weight-lifters, throwers, runners, soccer players, swimmers and controls. Bone density was ranked in the same order, with no difference between the swimmers and controls. Similar results have been obtained in female athletic groups, showing that women regularly participating in sports associated with high impact loading, such as volleyball and gymnastics, have greater bone densities in the spine, femoral neck and legs compared with swimmers or sedentary controls (Fehling *et al.* 1995). Once again the swimmers were not different from controls. Studies examining site-specific accretion of bone have demonstrated a greater bone density in the playing arm of professional tennis players, the difference being up to 30% (Jones *et al.* 1977).

An alternative approach has been to relate bone density to muscle mass, activity levels or aerobic capacity in different groups. Several studies show close links between muscle strength and/or muscle mass and bone density. In some cases, BMD was predicted by muscle groups associated to the bone of interest (e. g. quadriceps and femur), whereas the lumbar spine can be predicted from more distant sites such as the elbow flexors and quadriceps.

Relationships between cardio-respiratory fitness and bone density are more equivocal, possibly due to the method of fitness assessment and the site chosen for bone density measurement. Studies relating physical activity levels (assessed by questionnaires and interviews) and bone density have generally suggested that people participating in physical activity have greater bone density than sedentary individuals (Gutin & Kasper, 1992).

INTERVENTION STUDIES

The ultimate test of whether an exercise regimen is effective in improving bone mass is the intervention study. It is beyond the scope of the present review to discuss the many different studies in the literature and the reader is referred to several excellent, in-depth reviews (Gutin & Kasper, 1992; Marcus *et al.* 1992; Forwood & Burr, 1993). There are, however, several problems in interpreting the results as the type of subject, length of study, measurement techniques and measurement sites all vary enormously. In addition, the authors do not always provide any details of the exercise regimens used.

The American College of Sports Medicine has provided a series of principles which need to be considered when planning or interpreting the results from intervention studies involving training of any aspect of the musculo-skeletal system. These are as follows:

1. Principle of specificity: only sites which are loaded by the exercise could respond as the effects are localized;
2. Principle of overload: to effect a change in bone mass the training stimulus must exceed the normal loading experienced in everyday life;
3. Principle of reversibility: any positive effects of increased activity will be lost if discontinued;
4. Principle of initial values: those people with the lowest BMD at the start of training will have the greatest capacity to improve BMD if expressed as a percentage change;
5. Principle of diminishing returns: each person has an individual biological ceiling that determines the extent of a possible training effect. As this ceiling is approached, gains in bone mass will slow and eventually plateau.

In the following discussion of different intervention studies, I will aim to highlight the importance of these five principles.

ENDURANCE EXERCISE

Endurance exercise is a term which covers a wide spectrum of different activities ranging through walking and jogging, aerobics and conventional keep-fit classes. The activity typically comprises repetitive movements involving relatively low muscle forces. One of the earliest studies to investigate whether exercise could affect the rate of bone loss used a mixed programme, including walking and running exercises, floor exercises and ball games (Krolner *et al.* 1983). After 8 months there was an increase in spine BMC (mean 3.5%), but not forearm BMC, in the exercisers, which was significantly different from the decrease seen in the controls. The women studied all had previously suffered a Colle's fracture. The

lack of effect on the forearm was not surprising as this area was not particularly targeted by the exercise, emphasizing the principle of specificity. A later study compared a similar aerobics class to one in which additional low-intensity strengthening exercises were incorporated (Chow *et al.* 1987). The subjects were healthy post-menopausal women with no previous history of fractures. Bone mass was measured using neutron activation which gives an integrated Ca index for the skeleton. Both exercise groups showed an increase in Ca index compared with controls, but there was no significant difference between the two exercise groups. This suggests that adding the low-intensity strengthening exercise had no added beneficial effect. The measurement technique, however, was unable to detect site-specific effects. As weights were attached to the wrists, an increase in forearm BMD in that group might have been expected.

Further evidence for the beneficial effects of aerobic training on spine BMC in post-menopausal women was provided by Dalsky *et al.* (1988). Their protocol was more complex, in that after 9 months of training, the exercise group was further divided so that some continued training for a further 13 months whilst the others stopped training and were remeasured to assess the detraining effect. The exercise regimen included walking, jogging and stair climbing. After 9 months there was a significant increase in BMC in the exercise group of about 6%, this was maintained in those who continued training. Detraining resulted in a return of BMC to baseline values. A confounding feature of this study was Ca supplementation for those women on a daily intake of less than 1500 mg/d. This study highlights two more principles: (1) that of diminishing returns as the improvements remained, but did not increase further in the second training period; (2) that of reversibility, as the improvements were lost once training was discontinued. A further point highlighted by this study was that not all women in the exercise group showed an increase in BMD; over the first 9 months some showed decreases as great as the controls. This demonstrates the large variability in response to training which may reflect genetic differences, the intensity with which the individuals trained, or differences in the initial BMD.

WALKING

A number of studies have investigated the effects of walking on BMD, and the majority have found little, or no, effect. Martin & Notelovitz (1993) studied the effects on lumbar-spine and forearm BMD of 12 months of treadmill walking at 70–85% of the subjects maximum heart rate, together with Ca supplementation. Despite improvements in maximum aerobic capacity (V_{O_2max}), there were no significant increases in BMD in the exercise group compared with controls. Further analysis was carried out by dividing the group on menopausal status. Those less than 6 years post-menopause had an attenuated rate of bone loss at the spine compared with a matched control sub-group. This effect was not seen at the forearm. The latter is not surprising as the forearm was not targeted during the training. Nelson *et al.* (1991) compared supervised walking and either a moderate- or high-Ca diet (adjusted by supplementation) with similar Ca intake control groups. The only site which showed an effect of exercise, independent of Ca intake, was the spine; no effect was seen at the hip. An earlier study, using a similar exercise regimen but no dietary adjustments, found no effect of walking on spine BMD (Cavanaugh & Cann, 1988).

Hatori *et al.* (1993) compared the effect on spine BMD of outdoor walking above (high intensity) or below (moderate intensity) the anaerobic threshold for 7 months. The intensity was monitored by measuring heart rate, previously determined on treadmill testing. Control and moderate-intensity groups demonstrated a similar loss of bone, whereas the high-intensity group showed a moderate improvement (1.1%). It is unlikely, however, that

women would naturally adopt or maintain such an intense walking speed without supervision and feedback; therefore, the practical application of this finding is questionable.

HIGH-RESISTANCE TRAINING

Work investigating the osteogenic effect of different loading cycles in animals has indicated that strain magnitude is more important than the number of strain cycles (Rubin & Lanyon, 1984, 1985). In terms of exercise regimens used by human subjects, this type of strain environment more closely resembles resistance (or weight) training rather than endurance training. A number of studies have investigated the effects of resistance training on BMD and, as with the previous studies discussed, the results are inconclusive. In early post-menopausal women, Pruitt *et al.* (1992) found that 9 months of weight training had a moderate effect at the spine (+1.6%) compared with a decrease in the controls (-3.6%). There was no significant effect of the training at either the femoral neck or distal wrist. In an older group of women (65–79 years) they compared the effect of a low- and high-intensity weight-training regimen but found no effect of either regimen on the BMD of the hip and spine, despite improvements in strength (Pruitt *et al.* 1995). In a wider age-group (50–70 years), Nelson *et al.* (1994) found a significant effect of a 1-year high-intensity weight-training programme on the femoral neck and lumbar spine BMD. The exercising subjects also showed improvements in strength, balance and customary physical activity. No comment was made about whether the effects were greater in women more recently menopausal. The evidence from the weight-training studies suggests that improvements in bone density can occur, but are no greater than those observed following endurance exercise which may be better tolerated in the older age-groups.

EXERCISE AND OESTROGEN

A few studies have investigated the effects of exercise together with oestrogen supplementation *v.* oestrogen supplementation alone. Notelovitz *et al.* (1991) found that 1 year of multi-gym exercise and oestrogen resulted in significant increases in spine, total body and radial BMD in surgically-menopausal women. Those on oestrogen alone maintained, but did not increase, BMD at any site. At the spine the increase in the exercising group averaged 8.3%, which is large compared with many of the other studies. In an 11-month study of women aged 60–72 years, Kohrt *et al.* (1995) found that exercise, mainly involving jogging, walking and stair climbing, had an additive effect on BMD at the lumbar spine and greater trochanter compared with oestrogen alone. It would appear, therefore, that exercise can enhance the well-known beneficial effects of oestrogen replacement on BMD in oestrogen-deplete women.

THE HIP AND HIGH-IMPACT FORCES

Although several of these exercise interventions have shown improvements at the spine, few have been able to increase BMD at the hip. In terms of cost and morbidity, this is the most serious fracture site. The vertebrae have a high trabecular bone content which may adapt more easily to an osteogenic stimulus because of the high surface area and, therefore, greater metabolic activity, compared with a site with a higher cortical bone component, such as the hip. Another problem with the hip is designing an exercise which generates sufficient and unusual high-impact forces different from those experienced during normal

weight-bearing activities. With this in mind, Bassey & Ramsdale (1994) investigated the effect of high-impact work (mainly jumping) on BMD in premenopausal women. After 6 months, the high-impact group had a significant increase in trochanteric BMD of 3.4%. This study was followed-up in healthy, post-menopausal women (50–60 years), using heel drops rather than jumps (Bassey & Ramsdale, 1995). Heel drops were chosen to be safer and more feasible in this age-group. After 1 year, however, there were no significant differences in changes at the hip, spine or radius between the exercise and control (low-impact) groups. The authors speculated that the forces generated at the hip during this form of exercise were not sufficiently different from those achieved during brisk walking.

In light of the encouraging findings by this group in premenopausal women, we, together with the London YMCA, adapted keep-fit classes designed for over 50-year-olds (Welsh & Rutherford, 1996). The new exercises which were incorporated included stepping at a low speed, jumping, skipping, marching and side stepping. The subject group included post-menopausal women and men over 50 years. After 1 year there were significant increases in BMD at the femoral neck and greater trochanter compared with a non-exercising control group. No changes were seen at the spine or total body. A small number of subjects continued exercising for a further 1 year and the changes at the hip were maintained and significant increases were seen at the spine. The extent of the changes was similar in the men and women. The classes were well tolerated and did not result in any injuries. The improvements in bone density were accompanied by increases in quadriceps muscle strength and flexibility which may be important in reducing the incidence of falls.

OPTIMIZING PEAK BONE MASS

As treatments for osteoporosis are limited, the most effective way of decreasing fracture incidence is prevention. One of the most effective methods is to optimize the attainment of peak bone mass during the 3rd and 4th decades. Again the question of the most suitable form of exercise has been addressed. Snow-Harter *et al.* (1992) carried out one of the few comparative studies of endurance *v.* resistance training in premenopausal women. They compared an 8-month running and weight-training regimen in women with a mean age of 20 years. Both exercise groups showed a moderate improvement in lumbar spine BMD of just over 1%, which was significantly different from that of a non-exercising control group. No improvements were seen at the hip. These results are similar to those seen in post-menopausal women. In contrast to these findings, Rockwell *et al.* (1990) reported a significant decrease in spine BMD of 4% in slightly older women (30–45 years) following a 9-month weight-training programme. No change was seen in controls. Both studies supplemented the subjects with 500 mg Ca/d. The only real difference between the two was the difference in age. It is difficult, therefore, to understand why, in the study of Rockwell *et al.* (1990), exercise should have caused a decrease in BMD.

The use of high-impact exercise in women aged 35–45 years was investigated by Heinonen *et al.* (1996). The high impact component of the regimen involved either jumping or stepping. Changes in BMD were greater in the exercise group at weight-bearing sites such as the hip, spine and calcaneus. At the femoral neck the difference between control and exercise groups was significant. These results confirm those of Bassey & Ramsdale (1994) for premenopausal women and those of Welsh & Rutherford (1996) for older men and women. Heinonen *et al.* (1996) also found significant improvements in muscle power and dynamic balance following the exercise, these being implicated in the risk of falling.

THE 'DANGERS' OF EXERCISE

'Exercise is good for you' but is it always? There are at least two examples when, in terms of osteoporosis and fractures, this statement is not true. The first is exercise which might actually increase the risk of fracture. A question commonly asked by therapists and patients with osteoporosis is: 'what is the best type of exercise which is safe to use in women with established osteoporosis or a known low BMD?' Unfortunately, we do not know the answer yet. The studies described previously have mainly involved healthy women with no history of fractures, apart from Colle's fracture. Undoubtedly some subjects would have had a low BMD and there have been no reports of fractures occurring because of the exercise interventions. Clearly one should be wary of using heavy weights or high-impact forces where the BMD is beneath the fracture threshold.

One form of exercise has been identified as unsuitable for those with low spine BMD. In a retrospective study of fifty-nine patients with post-menopausal osteoporosis, Sinaki & Mikkelsen (1984) assessed the effect of different prescribed therapeutic back exercise programmes on further osteoporotic changes to the vertebrae assessed on anteroposterior and lateral X-rays. Patients were initially divided into four groups: (1) spinal extension; (2) spinal flexion, e.g. sit-ups; (3) extension and flexion; (4) either no exercise or head-lifts (isometric exercise of abdominals). Follow-up ranged from 1 to 6 years. A significantly greater percentage of further wedge or compression fractures occurred in the two groups using flexion exercises. This strongly suggests that this type of exercise should be avoided where there is uncertainty of the strength of the vertebrae.

At the other end of the age spectrum, another group which may be put at increased risk of osteoporosis are young women participating in high-intensity exercise, particularly runners, triathletes and ballet dancers. Awareness about the role of exercise and physical fitness for health has encouraged people to take part in sport and exercise in increasing numbers. Amongst younger women aerobic exercise is increasingly in use as a method of weight control, and in female athletes, including prepubertal girls, the levels of training intensity have increased dramatically. With this increase in the level of activity and intensity of effort, a number of adverse effects have emerged. Amongst female runners menstrual abnormalities and stress fractures are now a common problem. Intense physical training, particularly endurance exercise, can disrupt the normal control of ovarian function leading to either oligomenorrhoea (irregular menstrual cycles) or amenorrhoea (cessation of menstrual function). This leads to a reduction in oestrogen levels similar to the post-menopausal state. It is estimated that at least 50% of competitive female athletes experience oligomenorrhoea or amenorrhoea compared with 5% in the normal population (Carbon, 1992). Despite their high levels of activity, these women can lose bone, particularly in the lumbar spine (Drinkwater *et al.* 1984; Rutherford, 1993). A low bone density may put the athlete at increased risk of stress fractures in the short term (Myburgh *et al.* 1990) and osteoporosis later in life. In severe cases, osteoporotic fractures can occur, even in the young athlete (Wilson & Wolman, 1994). There needs to be greater awareness amongst coaches, sports scientists and doctors, and the athletes themselves about the potential risks of menstrual disturbances on the skeleton.

CONCLUSIONS

The evidence is growing that certain types of exercise can help maximize peak bone mass in the growing skeleton and reduce or reverse the age-related loss later in life. The optimal form, intensity and frequency of exercise remains obscure. For the spine, aerobic exercise classes carried out two to three times per week for 45–60 min appear to be able to improve

bone density by the order of 2–5 %. Higher-impact exercise appears to be required for the hip, but care needs to be taken when using this form of exercise in an elderly individual. Many aspects of physical performance decline with age. To be safe, the exercise protocol needs to be designed specifically for the age, health and ability of the individual. All exercise should be progressive to change the strain on the bone as it adapts and needs to target the site of interest. Even if an exercise modality has not proven beneficial for bone density, it may have many other health benefits which in turn could result in the individual being at a lower risk of falling, and ultimately increase daily activity levels.

The final test for the effectiveness of exercise in the prevention of osteoporosis, is not whether bone mass is improved but whether fractures are reduced. An excellent review of epidemiological studies investigating the link between treatment strategies and hip fracture incidence (Law *et al.* 1991) identified regular physical activity as being the most important preventative measure against hip fractures, with the risk in those who took regular exercise being halved.

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