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ACADEMIC LITERATURE REVIEW

Osteoporosis, falls and exercise

Agustín Meléndez-Ortega

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Abstract Osteoporosis, a manifestation of bone atrophy that leads to great susceptibility to fractures, is a very important public health problem today because of its great morbidity, mortality and important economic repercussions. It is a problem that will tend to become more serious with the increase in the number of elderly persons. Bone mass is gained during adolescence, reaches a plateau during the third decade and remains stable until approximately age 50, after which a progressively gradual loss is observed. There is no real cure for osteoporosis, but a series of strategies can be used to reduce bone loss and improve bone mass. Osteoporosis has been considered a disease that accompanies the process of ageing; however, this fatalistic attitude should be discarded, as it is possible to correct and decrease the risk factors. Intervention strategies are based on three pillars: nutrition, physical activity and pharmacological agents. Physical activities and exercise programmes are important because they not only can counter the loss of bone mass but also improve neuromuscular capacity, maintaining and increasing strength and muscle mass, which can help to avoid falls and reduce their impact and consequences. The general principles that apply to any exercise programme also apply to preventing bone mass loss. They also can be applied to persons with osteoporosis. However, to understand the peculiarities of these programmes, the propensity for suffering fractures of these former groups should be kept in mind. Special care should be taken to avoid falls and injuries. Weight-bearing exercise and resistance training are recommended for the prevention programmes. Other activities such as tai-chi, dancing, gymnastic or callisthenic exercises can help to improve balance, gait and muscle coordination and diminish the risk of falling. These programmes should be complemented with postural education and a series of safety precautions.

Keywords Osteopenia · Weight-bearing exercise · Ageing · Physical activity · Resistance training · Fall prevention

A. Meléndez-Ortega (✉)
Facultad de Ciencias de la Actividad Física y del Deporte—INEF,
Universidad Politécnica de Madrid,
Martín Fierro s/n,
Madrid 28040, Spain
e-mail: agustin.melendez@upm.es

Introduction

Osteoporosis is a manifestation of bone atrophy that leads to great susceptibility to fractures, which occur even as a result of small trauma [29]. It is defined as a decrease in bone mass per volume in terms of what is considered normal for a certain age, sex and race [59]. Bone decrease is asymptomatic, and in fact, its clinical manifestations derive from its main complication, fractures [59]. The most common fractures occur in the spine, wrist and hip and are not uncommon in the ribs, humerus and pelvis [29, 59]. Often, osteopaenia, which is a decrease in bone mineral density (BMD), is also considered osteoporosis [29], but osteoporosis consists not only of a reduction in bone mass but also of important changes in trabecular architecture, such as trabecular perforation and loss of connectivity [73]. The World Health Organization offers the following diagnostic criteria for osteopaenia and osteoporosis: Osteopaenia is present when BMD is greater than 1 standard deviation (SD) but less than or equal to 2.5 SD below normal values for young adults; osteoporosis is present when values are greater than 2.5 SD below normal peak bone mass [57, 81].

The decline in bone mass has been reported to begin as early as the second [60], third [28], fourth [41] or fifth [2] decades of life. Axial bone loss can occur as early as the third decade of life [32, 48, 49], and data on the iliac crest have suggested that trabecular bone mass can decline significantly in women before menopause. However, these data are questionable because of the characteristics of the samples and a number of geographical, ethnic, dietary and physical activity differences within and among study populations, which could account for the differences observed in the literature. Cross-sectional studies have shown an increase in mineral bone content in athletes and individuals who exercise regularly. Longitudinal studies have also shown that exercise can stimulate bone hypertrophy and/or prevent bone involution [68]. Adequate nutrition and weight-bearing physical activities are necessary for maintaining and maximizing bone mass [25].

Osteoporosis has been considered a disease that accompanies the process of ageing; however, this fatalistic attitude should be discarded. It is possible to correct and decrease the risk factors, as the illness can be detected in its early stages, engendering corrective measures, and steps may be taken to prevent it, given that the disease is considered to be the result of an inadequate accumulation of bone tissue during growth and/or excessive loss thereafter [59]. For this reason, it is important to emphasise the use of physical exercise during growth, to try to increase bone deposits.

Exercise is still important later on because it not only counters bone mass loss but also improves neuromuscular capacity, thus maintaining and increasing strength and muscle mass, which can help to avoid falls and, if they happen, reduce the impact and consequences. This article will therefore review some structural and functional aspects of bone and then discuss the different factors that influence its remodelling, emphasizing those aspects associated with physical activity.

Bone remodelling

The mechanisms by which bone responds to functional loading are poorly understood, but there is little dispute that bone adapts to imposed stress or lack of it, by forming or losing tissue (Wolff's Law). This process is mediated by remodelling, a continuous cycle of destruction and renewal of bone. Remodelling is accomplished by individual, independent bone-remodelling units, which are comprised of bone-reabsorbing osteoclasts and bone-forming osteoblasts. In a maintenance situation, remodelling may be somewhat inefficient because small deficits appear to persist at the completion of each cycle. Over the years, these accumulated deficits account for the bone loss associated with age [47]. This conclusion is based on the decrease in mean wall thickness of the trabecular bone from the iliac crest [40]. When stress is applied in excess of normal levels, osteoblastic activity exceeds osteoclastic reabsorption and bone hypertrophy occurs, with a consequent net gain in bone [7]. If reabsorption is greater than formation, the result is a net loss [73]. Thus, following Carter [13], we can conclude that osteoclastic activity removes damaged material so that osteoblasts can deposit matrix and minerals along the paths of imposed stress. When damage is gradual, bone mass increases. However, with a high rate of damage, bone formation may not keep up with accumulated fatigue damage, and fracture may result [73].

On a daily basis, the skeleton is subjected to external ground reaction forces and forces generated by muscle contraction. These forces can be classified into three types: (1) compressive forces or stress, which develops if loads are applied so that the material under consideration becomes shorter, e.g. the effects of body weight on the calcaneus in the standing position, (2) tensile forces or stress, which develops when bone is stretched, as when a person is hanging on a bar, and (3) shear forces or stress, which develops when one region of the material slides relative to an adjacent region, e.g. in up and down jumps, where shear stress appears in the proximal femur end [14]. These forces lead to alterations in bone shape and, to a large degree, determine its strength. All forces acting on the bone produce strain of some magnitude, and the amount of strain a material is able to withstand determines the strength of that material. Strain is defined as the change in dimensions produced by force divided by the original dimensions [73]. Strain is usually defined as a percentage change in the length or relative deformation [14]. Loading creates stresses within a bone, which may stimulate either external or internal remodeling or both and lead to a change in shape and possibly in bone density [73]. If accumulated strain over time remains constant, bone will persist in a state of equilibrium. If strain increases, bone is lost until a new equilibrium is reached. This is the case in immobilisation or lack of gravity as in space flights. Studies by Rubin and Lanyon [61, 62] indicate that an optimal level of strain is necessary to maintain bone mass and that bone mass is well correlated with functional loading. Their studies suggest that increasing the number of cycles results in no additional increase in bone mass. Whalen et al. [77] concluded that load magnitude was a more important determinant of bone density than the number of repetitions. At the other end of the spectrum, it is important to remember that the application of repetitive strains beyond physiological limits could lead to damage and eventual fracture [73]. According to these ideas, exercise training such as weight training, in which load is increased, would be more effective in improving bone mass than would be jogging, in which repetitions are the primary stimulus. The comparison of young active individuals who carried out programmes of this type with sedentary controls and weight lifters showed greater bone density values in the former [9, 31]. We will return to these aspects later on.

Changes in bone mass

Bone loss in women is a result of both ageing and menopause. There is agreement that trabecular bone loss begins before age 50 and increases at menopause in women [73]. In addition to a decrease in functional capacity as a consequence of sedentary lifestyle, middle-aged women may be affected by a loss of bone integrity aggravated by postmenopausal hypo-oestrogenism, low calcium consumption and a lack of physical stress [69]. Irrespective of the population studied, it can be observed that women show a greater bone loss with age than do men [50]. Women reach their maximal bone mass at approximately 35 years of age, after which annual loss is considered to be approximately 1% of bone mass. Men also reach their maximal bone mass at about 35, but the loss they experience is less and more gradual: 0.4–0.5% annually and only after the age of 50. Furthermore, bone loss accelerates in women after menopause, reaching 2 to 4% annually for 4 or 5 years, after which loss rate returns to about 1% per year. This reduction can reach 30% of bone mass in women at 70. Men, who begin with greater bone mass and experience a lower loss rate, are not generally at risk for fatigue fractures until the eighth decade of life [14, 50]. However, as Schnirring states [63], it is expected that the number of men suffering osteoporosis will rise dramatically as more men live longer. As men age, they do not undergo an intensive phase of bone loss as do menopausal women, but by age 65 to 70, men and women lose bone at similar rates, and at a more advanced age, 30% of hip fractures occur among men [16]. At least some data have also shown that because men develop osteoporosis at an older age, hip fracture mortality is greater in men than in women [3, 58]. It is for this reason that Campion and Maricic [11] recommend that physicians monitor certain men patients, those with more than 1–1/2 in. of height loss and those whose distal ribs touch the pelvic rim, for asymptomatic vertebral fractures.

Post-menopausal loss Two issues arise when considering the changes in trabecular bone loss that occur at menopause. The first is whether bone loss begins around the time of menopause; the second is whether menopausal loss subsides over time. As has been pointed out before, all studies confirm that if bone loss has not started at an earlier age, it certainly is present during the menopausal years. The majority of studies confirm that trabecular bone loss accelerates at menopause [73]. Gallagher et al. [26] reported the largest decrease in density to occur in the first 5 years after menopause. They found a decline of 3.4% per year in the second year, 1.7% in the fourth year and 0.8% in the ninth year. Cann et al. [12] found stable values for trabecular bone until menopause, which was followed by a rapid decline for 5–8 years, then a continued but slower decrease thereafter. Other studies have found similar trends (loss from 2 to 8%/year) from ages 50 to 60. Furthermore, an accelerated loss of trabecular vertebral bone has been demonstrated after surgical menopause [27].

Physical activity

The effects of physical activity can be separated into five research categories: (a) cross-sectional studies, (b) intervention studies, (c) muscle mass, muscle strength and BMD, (d) cardiorespiratory fitness and BMD and (e) reproductive endocrine status and physical fitness [73].

Cross-sectional studies Comparisons of active and sedentary populations at single points in time generally lend strong support to the notion that a positive relationship exists between activity and bone density [73]. Athletes, tennis players and experienced runners have higher bone density than non-active controls and demonstrate specificity of bone mass accretion in relation to activity mode. Bone mineral content of the radius was higher in tennis players and swimmers, and lumbar spine density was higher only in tennis players, indicating the potential role of weight-bearing activities in bone mass accretion [35, 54].

With regard to the importance of weight bearing to the skeleton, some studies suggest that loads other than those generated by gravity, such as muscular pulling, actively stimulate bone deposition. Davee et al. [20] found that young women who supplemented aerobic exercise training of only 1 h per week had higher spine densities than women who were sedentary or participated in aerobic exercises only. Additionally, Orwoll et al. [54] reported that radial and vertebral BMD were higher among men who swam regularly than non-exercising men, suggesting that although swimming is considered a non-weight-bearing exercise activity, its contribution to BMD may occur through loads created from high intensity muscular activity. The resistance offered by the water constitutes the stimulus that increases muscular activity.

With regard to the elderly, it is important to emphasise that not only is bone density higher in physically active people, which can be very significant when trying to prevent osteoporosis by increasing peak bone mass, but also the literature suggests that increased activity may be associated with a lower rate of age-related bone loss [35]. Thus, a comparison of older athletic women with younger athletic women who exercise at least three times a week, 8 or more months of the year, for a minimum of 3 years, showed that middle radius and lumbar spine values for the older women were similar to those of the younger athletic women. During this period, the control group formed by women older than 50 showed an annual decrease of 0.7% in spine density [4]. Other studies have also found a relationship between muscular strength, physical fitness and body weight but not in postmenopausal women (see below).

Intervention studies Intervention studies investigate the effects of an imposed exercise programme on BMD. In several studies, postmenopausal women who performed callisthenics and light aerobic exercise three times a week for 30–50 min per session during 8 to 48 months [41, 69–71] showed significant changes in lumbar spine and total body calcium even in a period of less than 12 months. No significant changes in bone mineral content of the radius were observed [41]. However, despite the fact that the majority of programmes that affect BMD in the spine and lower limbs imply exercises like walking or weight-bearing aerobic activities, differences have been observed in the wrist and in the distal part of the forearm (radius). Similarly, some studies have found that BMD was favourably affected by programmes that included muscle-conditioning exercises with weights for the upper body but not for those that used only weight-bearing activities [71].

Smith et al. [69] present some data that can help us to interpret the differential effects of exercise programmes on different areas of the skeleton. It seems logical that for a particular zone to be affected, it should be exposed to stimuli that produce a specific effect on it. These authors studied 200 women varying in age from 35 to 65, of whom 80 carried out a specific training programme and 120 served as a control group. The duration of the exercise programme was 36 months. Results demonstrated a significant decline in bone mass in the exercise group during the first year, followed by increases in radial densities over the following 24 months. However, the observed increases did not make up for the loss during the first year. The study was extended to 48 months after reporting that the data for the first year were not reliable because of problems with equipment quality control. Data for the third year showed that loss rates of the radius and ulna significantly decreased in the exercise group compared to the controls. On examination of the exercise programme, it is interesting to note that in the first year, the programme consisted of weight-bearing activities, whereas during successive years, additional emphasis was placed on upper body strength [70].

The site selected to show the changes is an important issue. For example, changes have not been observed in the density of the forearm of postmenopausal women after carrying out weight-bearing activities [78]. Significant increases were shown in the calcaneus of a group of women runners after a 9-month programme [79]. After performing a combination of bending, loading compression and torsion exercises designed to load wrist and forearm, the postmenopausal exercise group had a significant increase in forearm bone density (3.8%) after following the programme three times a week for 5 months [5]. Another interesting aspect that emerged when studying the exercise programme, which included trunk extension exercises, was its effect on vertebral fractures. The group that carried out this programme suffered fewer fractures than the one which carried out flexions. A possible explanation is that extension exercises strengthen the back but flexion exercises do not [64].

Another aspect that is important for obtaining benefits from physical training is progression. To improve physical capacity, physiological overload must be maintained. Therefore, it is important to progress in training, i.e. we should increment the weight that is moved or, in this case worn, to maintain the stimulus to realise additional benefits. In this case, wearing a weighted vest would be a way to apply the training principle of progressively incrementing the physiological overload to provide a stronger stimulus than just walking. Snow et al. [72] found this procedure to be an effective system, and in a long-term study, the procedure prevented hip bone loss in postmenopausal women.

It has already been pointed out that weight-bearing exercise programmes are generally recommended, but certain studies indicate that resistance exercises can be more powerful for promoting bone accretion because of the different forces produced at the lumbar vertebrae level. For example, in comparing fast walking with jogging, the forces were 1 and 1.75 times body weight, respectively. On the other hand, during weight training exercises defined as non-weight-bearing activity, the load on the lumbar vertebrae can be as high as five to six times body weight [31].

High-impact exercises are another way to impose a higher intensity load on bone and can be utilised for stimulus progression to facilitate greater adaptation. In a randomised, controlled trial involving 98 healthy, sedentary, 35- to 45-year-old women, those who participated in 18 months of three weekly sessions of progressive high-impact training had significantly greater increases in femoral neck BMD than sedentary controls (+1.6% vs −0.2%, respectively) [34]. Just as noted, impact intensity has been used to explain the differences found between female gymnasts and swimmers and controls after a 12-month programme. If done regularly, these type of exercises can help to reduce the risk of future fractures, as they facilitate the accretion of bone mass [75].

Muscle mass, muscle strength and bone mineral density We should not forget that the skeleton is a dynamic tissue, so it is not surprising that through its connections with muscle, it exhibits changes similar to those observed in muscle. Sarcopaenia, the age-related loss of muscle, inhibits mobility, increasing the risk for developing many diseases including diabetes, arthritis, heart disease and, what it is important in the context of this review, osteoporosis [76]. It increases the risk of weakness, functional decline, impaired gait, falls, infections, glucose intolerance and osteoporotic fractures. Sarcopaenia is linked to osteoporotic problems and for this reason has also been treated in the context of osteoporosis.

The estimated loss of bone from its peak in young adulthood to 80 years of age is comparable to the reported 35–45% decline in muscle strength during the same lifespan [36]. Several authors have studied the relationship between BMD and muscle strength, which depends to a large extent on muscle mass. Significant correlations have been found between different parameters of muscle mass and bone density and between vertebral ash weight and psoas muscle weight in 46 routine autopsies, which suggests a relationship between the strength of a specific muscle group and the corresponding bone [1, 21, 64–66]. Some studies do not find this relationship significant. Sinaki et al. [67], for example, did not find significant changes in BMD of the spine after a 2-year exercise programme that entailed non-weight-bearing activities but increased the isometric strength of the back. However, this could be attributed to the fact that the type of programme used loads to improve muscular resistance but not strength, and the magnitude of the load may not have been sufficient to achieve the necessary stimulus to provoke adaptation.

The effect of muscular activity on BMD has been assumed to be site specific. However, other aspects make this statement a little more complex. Pocock et al. [56] evaluated pre- and post-menopausal women on the strength of biceps brachii and quadriceps group, and BMD of the spine and proximal femur. They found biceps strength but not quadriceps strength to be a predictor of BMD at the spine and three regional sites on the proximal femur. For this population, muscle strength better explained the variance in BMD than age. Snow et al. have found similar results as well [73, 74]. It can be concluded that in some cases, the relationship between strength and BMD are specific. In other cases, however, muscle groups more distal to the spine and proximal femur significantly contribute to bone density. A possible explanation of this relationship may be that arm activity is linked to the simultaneous contraction of trunk-stabilizing muscles that directly exert forces on the hip and spine. Moreover, the length of the lever arm between arm muscles and the spine is considerably greater than that between back extensors and the spine, so that when lifting the same weight, loads on axial bone generated by arm activity exceed those generated by back extensors [45, 73].

Fiatarone et al. [23] have shown how progressive resistance training is feasible, safe and effective in a variety of settings such as nursing homes, chronic hospitals, outpatient clinics, continuing care communities and individual homes with elderly people even of a very advanced age (nonagenarians). Several studies have shown that progressive resistance training may lead to muscle hypertrophy, whereas cardiovascular endurance training does not in general improve either muscle strength or mass. The injury rate with appropriate exercises is very low, and very few medical conditions are incompatible with its usage. The benefits observed with these programmes include improvements in muscle strength, muscle mass, gait speed, balance, stair climbing ability, overall physical activity levels, functional status, morale, depression, sleep and nutritional intake. Muscle biopsy samples indicate activation of satellite cells and myogenic precursor appearance, as well as expression of developmental myosin and insulin-like growth factor I (IGF-I), all indicative of the plasticity and remodelling of the skeletal muscle.

There is evidence that high-intensity resistance training promotes bone maintenance in older women. High intensity can be applied using several weight machines that support the spine. People can then perform exercises in a sitting position with support for the back or use free weights in which muscles need to stabilise the body to maintain posture. Maddalozzo and Snow [46] compared the effects of a moderate seated resistance-training programme with high-intensity standing programmes on bone mass and serum levels of IGF-I and insulin-like growth factor binding protein 3 (IGFBP3) in healthy older men and women (54.6±3.2 and 52.8±3.3 years, respectively). High-intensity training resulted in spinal BMD gain in men (1.9%, $p<0.05$) but not in women. Moderate programmes produced no changes in either gender at this site. Increases were observed in the greater trochanter in men regardless of training intensity but not in women. Both men and women in the high-intensity group improved in trochanteric BMD. Both programmes improved total body strength (37.63%) and lean body mass (men 4.1%, women 3.1%). Neither circulating serum IGF-I nor IGFBP3 was altered by either training regimen. The authors concluded that although resistance training of moderate to high intensity produced similar muscle changes in older adults, a higher magnitude is necessary to stimulate osteogenesis at the spine. However, at the spine, intensity was not sufficient to offset low levels of oestrogen in early postmenopausal women, and bone changes were not accompanied by changes in circulating serum levels of IGF-I or IGFBP3.

Tissue plasticity or the ability to regenerate after stress has been a subject of investigation in ageing humans. Fiatarone et al. [24] explored the effects of a 10-week progressive resistance-training programme on muscle plasticity in frail elders, aged 72–98 years. Post-muscle biopsy specimens showed an increased appearance of IGF-I and regeneration potential from baseline atrophy. The 257% increase in strength after resistance training was associated with a 141% increase in ultrastructural damage and a 491% increase in IGF-I immunofluorescence staining. Because the IGF-I receptor plays a dominant role in muscle IGF-I signalling, the authors speculated that this increase in IGF-I receptor numbers together with markers of muscle damage and regeneration may expand existing knowledge regarding the IGF-I response to exercise stress in older adults. Later, Urso et al. [76] assessed the impact of 10 weeks of resistance training on markers of skeletal muscle plasticity and IGF-I receptor density in a sub-sample of subjects who in an earlier study had demonstrated enhanced immunohistochemical labelling of IGF after resistance training. The experimental subjects showed a 161±93.7% increase in Z band damage after resistance training. Myofibrillar central nuclei increased 296±120% (p=0.029) in the experimental subjects. Changes in the percentage of damaged Z bands were associated with alterations in the presence of central nuclei (r=0.668, p=0.034). Post-hoc analysis revealed that the relative pre–post percentage changes in myofibrillar Z band damage and central nuclei were not statistically different between the control and exercise groups. Exercise training increased myofibril IGF-I receptor densities in the exercise subjects (p=0.008), with a non-significant increase in the control group. The authors remarked that the labelling patterns suggested enhanced receptor density around the Z bands, sarcolemma and mitochondrial and nuclear membranes. Furthermore, these findings suggest that the age-related down-regulation of the skeletal muscle IGF-I system may be reversed to some extent with progressive resistance training and that skeletal muscle tissue plasticity in the frail elderly is maintained at least to some extent, as exemplified by the enhancement of IGF-I receptor density and markers of tissue regeneration [76].

Cardiovascular fitness and bone mineral density Some studies have found a significant relationship between cardiovascular fitness and bone density [15, 55], while others have found no differences between active groups and sedentary groups [7, 8, 18, 30, 52]. The relationship of cardiovascular fitness to BMD is probably due to the weight-bearing stimulation that activity itself provides to the skeleton.

Reproductive endocrine status and physical training It is now recognised that despite the beneficial effects of weight-bearing exercise (and probably resistance training) on BMD, severe and excessive exercise training together with deficient nutrition attributable to eating disorders may interrupt menstrual function and lead to bone loss and increased fracture risk [12, 22, 48]. This condition has become known as the ‘female athlete triad syndrome’ and is characterised by disordered eating, amenorrhea and osteoporosis. The loss of menstrual function has been clearly associated with a consistent decrease in trabecular bone despite apparent preservation of normal cortical bone density. Fortunately, reports indicate that although serious depletion of bone mass can occur in the amenorrheic athlete, a portion of this loss is potentially reversible [44]. It should be noted as well that in spite of often being amenorrheic, gymnasts demonstrate an exception to this rule; they typically have very dense bones. The large discrepancy in magnitude of the forces placed on the skeleton during different activities can explain the differences from other highly trained athletes, as much higher impact forces are generated in gymnastics [6]. However, it should be emphasised that in the case of women, excessive exercise can be contraindicated, as the hypo-oestrogenism associated with athletic amenorrhoea can lead to a loss of bone mass [68]. In the same way, it is advisable to underscore that today’s high incidence of cases of anorexia nervosa is a certain source of future problems.

To summarise, although results from cross-sectional analysis support a positive effect of exercise on BMD, results from longitudinal studies provide mixed outcomes. These results vary with the mode, duration, intensity and frequency of exercise. Most of the studies have used weight-bearing activities (walking, jogging, running, dancing) as the exercise intervention. However, when the programmes have been more intense, of longer duration or included exercises that overloaded the muscular system, a better osteogenic stimulus has been observed.

Exercise in the prevention and treatment of osteoporosis

Before addressing this topic, it is necessary to present some prior considerations. The problem is different for children or teenagers, for whom high impact activities like jumping are recommended, than for pre- or post-menopausal women or elderly men and women who may have weakened skeletal structures and should be advised to take extra caution with all exercises [37].

In the latter cases, exercise-related increases in bone mass are often quite modest or non-existent, or they may consist of reduced loss of bone mass. However, even the mere prevention or delay of bone loss without any gain is advantageous from a clinical point of view, given that maintenance of bone mass reduces fracture risk.

Five primary questions are of general interest when addressing the efficacy of exercise in the prevention and treatment of osteoporosis: (1) Can exercise maximise peak bone mass? (2) Can exercise forestall or minimise age-related losses? (3) Can exercise improve BMD in individuals with established osteoporosis? (4) Can exercise training replace oestrogen replacement therapy during the early post-menopausal years? (5) What type of programme is appropriate?

First, we should remember that there is an important genetic component, which means that individual differences may appear in the response to any given type of exercise.

Second, Wolff's Law establishes that bone will accommodate the habitual stresses that are imposed upon it, and once equilibrium is reached, bone mass will not increase over time. For added benefits, it would be necessary to increase the daily training schedule, i.e. making the training programme more progressive. The fact that some studies have not found differences after treatment may simply be due to not using a sufficiently strong stimulus to provoke change [37] or not using progression in the programme.

Third, we should also remember that training reaches a point of diminishing returns, so that benefits in terms of bone mass should be greater when exercise is imposed on sedentary individuals than when given to those who are already active [73]. We should not be surprised by the fact that exercise elicits the greater response from the bones of individuals with very low initial skeletal mass [19, 42], assuming the stimulus provided is adequate.

With regard to the fourth question, it would be naive and inappropriate to consider exercise as a replacement for hormonal therapy. It would seem logical to expect the possible osteogenic effects of pharmacological agents to be more effective if bones were subjected to mechanical stimuli, which determine their structuring. Although there does not appear to be a complete consensus on this, according to several authors [39, 53], oestrogen therapy and variable-resistance weight training increased BMD in surgically menopausal women [53], and hormonal replacement therapy (HRT) increased BMD after a supervised exercise programme [39]. However, we should point out the disagreement of Heikkinen et al. [33] with these results. When they combined HRT, two oestrogen–progestin regimes and exercise in healthy post-menopausal women and compared them with a control group that carried out exercise and took a placebo, no significant differences were found between the two treatments after 2 years of the programme. Future research should be directed at understanding the interactions of exercise interventions and hormone replacement in women of this age group [73], a similar approach to that of the ADFR (activate, depress, free, repeat) therapy but using exercise as well.

To address the fifth question, we should remember that the effects of exercise are site specific; that is to say, only bones that are loaded will benefit from activity. For example, running will not affect bones in the forearm [34, 37]. On the other hand, the programme must be continuous because of the principle of reversibility. In other words, if the stimuli are suppressed, in time, the effects achieved will be lost, as we see, for example, in situations of prolonged bed rest or weightlessness.

As mentioned, weight-bearing exercises like walking, jogging and running have been those most recommended. These activities could be done in such a way as to kill two birds with one stone, i.e. providing a stimulus for the skeleton while also training the cardiovascular system. The possible advantages of resistance exercises for muscle strengthening have also been pointed out. Some doubts have been cast about the possible effect of this type of exercise for promoting the accretion of bone mass. However, even without an effect on BMD, it has been shown that improving muscle strength reduces falls and therefore the risk of fracture, the worst problem of osteoporosis. Strengthening the quadriceps and gluteal muscles (leg and hip extension) enhances the ability to stand up safely from a seated position [6]. The question that arises is the advisability of using these muscle-strengthening exercises safely with frail elderly. The results of Dalsky et al. [18] indicate how lower intensity resistance training can be successfully introduced to this population. Based on these results, it seems reasonable to suggest that a combined programme of weight-bearing and resistance activity, modified as necessary for frail persons, is a rational strategy to provide optimal cardiovascular and skeletal benefits for healthy men and women of all ages [20, 23, 73].

While bone loss and disruption is the central process in osteoporosis, the clinical problem is fracture. Regular exercise is probably the only method that may prevent osteoporotic fractures by preventing osteoporosis and falls [37]. Cummings et al. [17] after a review of risk factors for hip fractures in white women concluded that exercise and particularly walking reduced the risk of fractures by preventing falls. Similar conclusions were reached by Nelson et al. [51]: that exercise improves muscle mass and strength and improves balance, gait and reaction time. Tai chi (and other exercises) improves balance as it focuses on posture and low velocity movements of the body [80]. In very old and frail elderly people, exercise can improve gait, balance, coordination, proprioception, reaction time and muscle strength. In this respect, a 30% reduction in the rate of falling after strength and balance training [10] is remarkable [43].

Programmes for people with osteoporosis

The general principles which apply to any exercise programme also apply to persons with osteoporosis. However, to understand the peculiarities of these programmes, the propensity of people with osteoporosis to suffer fractures should be kept in mind, and special care should be taken to avoid falls and injuries. Therefore, each session should include a warm up, a cool down and periods for flexibility training. It is important for the exercise programme to concentrate on improving factors that play a part in preventing falls, like a more stable gait, better balance, strength and the speed at which the person responds (reaction time). Prescriptions of aerobic training should not require very specialised recommendations apart from avoiding high-impact activities, in which case it is preferable to walk rather than run. With frail people, tennis for example is not recommended because of the risk of wrist injuries. Similarly, rowing exercises or those carried out on rowing-type machines should be avoided as the forces caused by trunk flexion will impose inappropriate pressure on the backbone. A typical programme could therefore begin with three sessions per week at 40–70% of the heart rate range, lasting for more than 20 min, or if necessary, it could begin with 3 to 5 min of aerobic exercise and then be gradually extended until the generally recommended time periods are reached. In the same way, if exercises like aerobics are used, care should be taken to avoid high-impact drills like jumping, especially on hard floors, and difficulty levels should be gradually increased, to avoid falls. It may also be advisable to omit exercises that involve unstable postures and thus unnecessary risks. In older persons, it may be appropriate to combine aerobic exercises with muscle-building exercises, and in general, weight-bearing exercises are recommended. Strength and flexibility training is also important. Muscle-building training could be alternated with aerobic exercises, even in the same session. It is important to remember that BMD in the wrist and forearm, frequent sites of fractures, are favourably affected by muscle-building programmes that include exercises for the upper limbs [71]

In populations with a high risk of fractures, safe alternatives should be sought for muscle building. For example, exercise in water can be useful because resistance in water can be varied by altering movement speed, surface area and amplitude to regulate intensity easily. At the same time, this medium supports body weight. Another alternative is to use chairs as a support or even to carry out exercises sitting down or with the help of a partner. In this case, people may feel more secure and less afraid of falling. Care must be taken to avoid slippery floors.

For individuals suffering from problems of balance, weight-bearing exercises should be very simple at first. Those who have suffered fractures of the spine should avoid flexion exercises when using resistance or in flexibility training. Persons who have had spine or hip fractures may have difficulty at first in a programme of weight-bearing exercises. For them too, exercises with chairs or in the water can improve strength and cardiovascular fitness.

Given that low body weight is often associated with osteoporosis, these persons should be encouraged to increase their energy intake and improve their nutrition. A final word should be added about the choice of surface on which exercises are performed. Cement or very hard floors are dangerous in that they can cause joint injuries and stress fractures. Similarly, slippery floors may cause falls. The ideal floor is resilient or made of wooden boards. Performing activities on elastic but not soft floors, such as Judo or gymnastic mats, can be another alternative to reduce the risk of fractures in case of falling. Equally important, sports shoes should be chosen, which help to diminish the effect of the continual micro-impacts.

Safety precautions

To conclude, it should be emphasised that prevention of falls demands more than exercise alone. For elderly patients especially, it is very important to support systematic fall-prevention programmes aimed at reducing the possible risk factors that abound in sports centres and the home such as dim lighting, loose carpeting and scattered toys and objects. Correction of vision and hearing deficits can also help elderly people to maintain their balance. If patients take tranquilizers or sleep medications, they should be cautioned about possible dizziness as a side effect. The use of trochanteric pads in high-risk patients can diminish the impact in case of falling [38].

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