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Review Article
Gómez-Cabello et al.
Training and Effects on Bone Mass in Older Adults

Effects of Training on Bone Mass in Older Adults

A Systematic Review

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Abstract**((Author: please note, we have deleted the headings from the abstract as we do not use headings such as these in Review articles.))**

It is widely recognized that the risk of fractures is closely related to the typical decline in bone mass during the ageing process in both, women and men. Exercise has been reported as one of the best non-pharmacological ways to improve bone mass throughout life. However, not all exercise regimens have the same positive effects on bone mass, and the studies that have evaluated the role of exercise programmes on bone-related variables in elderly people have obtained inconclusive results. This systematic review aims to summarize and update present knowledge about the effects of different types of training programmes on bone mass in older adults and elderly people as a starting point for developing future interventions that maintain a healthy bone mass and higher quality of life in people throughout their lifetime.

A literature search using MEDLINE and **the** Cochrane Central Register of Controlled Trials databases was conducted and bibliographies for studies discussing the effect of exercise interventions in older adults, published up to August 2011 were examined. Inclusion criteria were met by 59 controlled trials, 7 meta-analyses and 8 reviews. The studies included in this review indicate that bone-related variables can be increased, or at least the common decline in bone mass during ageing attenuated, through following specific training programmes. Walking provides a modest increase in the loads on the skeleton above gravity and, therefore, this type of exercise has proved to be less effective in osteoporosis prevention. Strength exercise seems to be a powerful stimulus to improve and maintain bone mass during the ageing process. Multi-component exercise programmes of strength, aerobic, high impact and/or weight-bearing training, as well as whole-body vibration (WBV) alone or in combination with exercise, may help to increase or at least prevent decline in bone mass with ageing, especially in postmenopausal women. This review provides, therefore, an overview of intervention studies involving training and bone measurements among older adults, especially postmenopausal women. Some novelties are that WBV training is a promising alternative to prevent bone fractures and osteoporosis. Because this type of exercise under prescription is potentially safe, it may be considered as a low impact alternative to current methods combating bone deterioration. In other respects, the ability of peripheral quantitative computed tomography (pQCT) to assess bone strength and geometric properties may prove advantageous in evaluating the effects of training on bone health. As a result of changes in bone mass becoming evident by pQCT even when dual energy X-ray absortiometry (DXA) measurements were unremarkable, pQCT may provide new knowledge about the effects of exercise on bone that could not be elucidated by DXA. Future research is recommended including longest-term exercise training programmes, the addition of pQCT measurements to DXA scanners and more trials among men, including older participants.

Keywords: adults; aging; bone; bone mineral density; elderly; exercise; sports-medicine; training.**((Author: the keywords will be removed once the article has been formatted into page proofs.))**

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1. Introduction

The WHO has defined osteoporosis as a skeletal disease characterized by "low bone density and microarchitectural deterioration of bone tissue with a consequent increase in bone fragility and susceptibility to fracture." [1]

Even when it has been shown that young adults and children can also develop osteoporosis,[2] this pathology is more commonly associated with old age, especially among women probably due to hormonal changes (e.g. reductions in estrogen)[3] and a decline in physical activity.[4]

It is widely recognised that the risk of fractures is closely related to the decline in bone mass during the ageing process, in both women and men.[5] Moreover, net bone loss is also accelerated with age. In men over 70 years of age, net bone loss occurred 2- to 4-fold faster compared with men aged under 60 years at baseline.[6] In postmenopausal women, data published by Nguyen et al.[7] showed that the rate of bone mineral density (BMD) loss progressively increased with age, −0.6%, −1.1% and −2.1% per year for the 60–69, 70–79, and ≥80 age groups, respectively. However, other research has estimated greater losses; women lose up to 5% of bone mass annually in the first few years after menopause, followed by 2–3% annual loss thereafter,[8] while men lose approximately 1–2% of BMD per year, starting from a higher baseline.[9]

Although it is known that an increase in levels of physical activity may lead to enhanced bone mass, it is suggested that the best way to improve all bone-related variables is to include specific exercise training programmes.

Several training methods have been used to improve bone mineral content (BMC) and BMD in prospective studies. However, not all forms of exercise have the same positive effects on bone mass and because of that, the studies that evaluated the role of exercise programmes on bone-related variables in elderly people have obtained conflicting results. Kelley et al.[10] showed through a meta-analysis that some types of exercise training do not improve femoral neck BMD in postmenopausal women and, recently, in a systematic review and meta-analysis, Nikander et al.[11] did not find any significant effects of exercise on bone strength from any training programme, which may partly be explained by the short duration and inadequate power of the few published trials. Guadalupe-Grau et al.[12] reported that studies performed in older adults show only mild increases, maintenance or just attenuation of BMD losses in postmenopausal women. Nevertheless, other meta-analyses showed very consistently that exercise training programmes have benefits in both the lumbar spine and femoral neck in postmenopausal women.[13,14] Moreover, a systematic review found that both impact and non-impact exercises have a positive effect on bone[15] and another recent article by Martyn-St James and Carroll[16] suggested that impact exercise in the form of jogging when combined with other low impact activity, such as stair climbing and walking, and programmes combining impact exercise with high-magnitude exercise in the form of resistance training, have a positive effect on preserving BMD in postmenopausal women. Thus, it is suggested that each kind of exercise programme has different effects on bone mass and risk of fracture in elderly people, but the literature still remains controversial.

Therefore, the aim of this review was to summarize and update knowledge about the effects of different types of training programmes on bone mass in older adults and elderly people, as a starting point for developing future interventions that maintain a healthy bone mass and higher quality of life in people throughout their lifetime.

2. Method

2.1 Data Sources and Search Strategy

We searched MEDLINE and **the** Cochrane Central Register of Controlled Trials databases (up to 2011) focusing particularly on the latest publications. To find additional articles, we examined evidence tables from earlier systematic reviews and consulted references of controlled trials when necessary. Two investigators independently examined each database to obtain the potential publication. The search was conducted up to and including 3 August 2011, using the following keywords: ‘exercise’, ‘training’, ‘bone mass’, ‘bone mineral content’, ‘BMC’, ‘bone mineral density’, ‘BMD’, ‘whole-body vibration’, ‘WBV’, ‘older adults’ and ‘elderly’, or a combination of them. The search strategy was modified for each database and explored, when possible, in order to maximize sensitivity and produce a comprehensive search. Terms were searched for title, abstract and subject heading.

2.2 Review Selection

Two reviewers independently examined titles and abstracts. Relevant articles were obtained in full, and were assessed against the inclusion and exclusion criteria described below. Inter-reviewer disagreements were resolved by consensus. Arbitration by a third reviewer was used for unresolved disagreements.

2.3 Inclusion Criteria

Criteria for inclusion were as follows:

1) Types of study: randomized and non-randomized controlled trials studying the effects of exercise training programmes on bone mass with or without co-existent treatments. Moreover, meta-analyses and systematic reviews were also included to study the background of this topic.

2) Types of participants: older adults and elderly postmenopausal women and men (average age ≥50).

3) Types of intervention: trials comparing the effects of following or not following an exercise training programme.

4) Types of outcome measures: BMC and BMD of whole body, lumbar spine, hip (femoral neck, trochanter, intertrochanter and Ward's triangle subregions), forearm, bone architecture (from quantitative computed tomography [pQCT]) and ultrasound parameters (broadband ultrasound attenuation [BUA], speed of sound [SOS] stiffness index).

2.4 Exclusion Criteria

The criteria for exclusion consisted of (i) studies in languages other than English or Spanish; (ii) studies without a control group; (iii) studies including only information on biochemical markers or number of fractures; (iv) unpublished data; and (v) studies with animals.

No statistical analyses or meta-analyses were conducted in this review.

2.5 Search Summary

Searches identified 786 potentially relevant articles and an additional 15 articles were identified through reference lists. Following review of titles and abstracts, the total was reduced to 124. Of these articles, 74 met the selection criteria and were included in this review (figure 1).

Fig. 1

2.6 Summary of Study Characteristics

The study characteristics are summarized in the document through different sections and in detail by specific tables using the PICO format:[17] patients or participants (P), intervention (I), comparison or control group (C), and outcomes (O). In order to facilitate the comparison between studies, we classified the trials as aerobic (n = 12), strength (n = 15), multi-component (18) or whole-body vibration training (10).

3. Results

3.1 Aerobic Training

One of the simplest and most accessible forms of aerobic exercise is walking. It appears to be the most common choice among older subjects because of its benign nature, low risk, lack of need of supervision and universal availability and, therefore, most of the research that studied the impact of aerobic training on bone mass is carried out with this mode of exercise. However, the results relating to bone mass obtained with this type of activity still remain controversial[18,19] (table I).

Table I

The first study that assessed the effect of an aerobic exercise programme that combined walking, jogging and stair climbing in postmenopausal women was carried out by Dalsky et al.[20] In this research, BMC at lumbar spine increased 5.2% after 9 months of training, whereas there was no change in the control group. After 22 months of exercise, BMC was 6.1% higher in the training group.[20] These positive effects of aerobic exercise on bone mass were also found by Chien et al.[28] This study reported that walking combined with stepping at a moderate intensity was effective in offsetting the decline in BMD in osteopenic postmenopausal women. After 24-weeks of training, the BMD of the lumbar spine (L2–L4) and the femoral neck in the exercise group significantly increased 2.0% and 6.8% and those in the control group decreased 2.3% and 1.5%. Nevertheless, it is not clear whether the same bone benefits would be obtained with the step training alone.

Cavanaugh and Cann[21] showed that a moderate brisk walking programme of 1-year's duration did not prevent the loss of trabecular bone density in the spine of early postmenopausal women. In this study, eight postmenopausal women participated in a progressive walking programme for 15–40 minutes 3 days per week. Several years later, it was shown that 9 months of aerobic training (walking, rowing and stair-climbing) had not had any impact on whole body, lumbar spine or femoral neck bone mass.[31] Similarly, Martin and Notelovitz[24] reported no effect at the spine or forearm in postmenopausal women after a 1-year treadmill walking programme with calcium supplementation. A study with similar characteristics showed that trabecular BMD of the lumbar spine (L1–L3), measured by computed tomography, increased significantly by 0.5% in exercising women and decreased by 7.0% in sedentary women, but neither exercise nor dietary calcium had an effect on the lumbar spine (L2–L4) measured by dual photonic absorptiometry (DPA), distal radius measured by single-photon absorptiometry (SPA), or total body calcium measured by *in vivo* neutron activation.[23] Other research study showed that a 2-year brisk walking programme (defined as walking at a pace that was faster than usual walking for the subject but not so fast as to be uncomfortable or to cause shortness of breath) was not enough to improve BMD in women but it may reduce loss of BMD at the femoral neck.[26] At the lumbar spine no difference between the brisk-walking and placebo groups was observed, although neither group experienced a fall in BMD at this site.

The positive effects of aerobic exercise have also been tested in more specific populations such as postmenopausal breast cancer survivors,[32] overweight and obese postmenopausal women participating in a weight-loss programme,[27,33] or osteopenic/osteoporotic elderly women.[30] In this research, walking or jogging was associated with decreases in body fat and a loss-halting, maintenance or improvement of BMC and BMD, showing that exercise may also induce favourable changes in bone mass in these specific populations.

The importance of intensity in a walking exercise programme was indicated by Hatori et al.[25] In a 7-month trial, they compared walking above (high intensity) or below (low intensity) the anaerobic threshold on spine BMD. The low-intensity group showed a similar loss of bone to the controls, whereas the high-intensity group showed a modest improvement.

The effect of aerobic aquatic exercise on bone parameters has also been tested. Ay et al.[29] examined the efficacy of an aquatic training programme on the calcaneal bone of postmenopausal sedentary women with low bone mass. In this population, submaximal aerobic exercise 3 times a week during 6 months was enough to improve up to 63% of the T-scores in the calcaneus.

Because of the fact that women are more likely to suffer osteoporosis, there is a lack of studies concerning men. To our knowledge, there is only one piece of research that studied the effect of aerobic exercise on bone mass among the elderly that included men. Blumenthal et al.[22] showed that 16 weeks of aerobic exercise combining bicycling, brisk walking, jogging and arm ergometry did not result in any bone mass change among elderly men and women.

In summary, because of the low impact of this type of activity, most of the studies that investigated the relationships between BMD and walking exercise reported no increases in bone parameters after a training programme. However, the fact that aerobic exercise may maintain or slow the loss of bone mass in elderly people must be considered an important outcome of this kind of exercise. Moreover, current studies show that an aerobic exercise programme may have more benefits for bone health when it includes activities of high impact such as jogging or stepping.

Studies examining the effects of aerobic exercise in older adults obtained disparate results, probably because of the age of the subjects, skeletal sites assessed, and the mode, intensity, duration and frequency of exercise that varied from study to study. This exercise intervention is not specifically designed to maximize loading forces to mechanically stress bone and induce changes in BMD, therefore, interventions that combine aerobic training with other forms of exercise that provide adequate skeletal loading may be of greater benefit in improving bone mass among older adults.

3.2 Strength Training

Strength training is one of the most frequent types of exercise programmes applied in order to improve bone mass in elderly people (table II). The increased mechanical stress on the bone provided by this type of training has been demonstrated as a causal factor of osteogenesis.[36]

Table II

Several studies showed that strength training is able to prevent bone demineralization in older women,[45,46] and also in men.[44] Bocalini et al.[45] evaluated the effects of strength training on the BMD of postmenopausal women without hormone replacement therapy. After 24-weeks of training, untrained women exhibited a significant percentage decrease in BMD at the lumbar spine and femoral neck, whereas the BMD was maintained in trained women at both sites. Similar results were found by de Matos et al.[46] in postmenopausal women with osteopenia or osteoporosis. After 12 months of weight-training exercise, a non-significant increase in BMD at the lumbar spine (1.17%) and non-significant decreases in BMD (0.71%) in the hip were detected among the trained group. On the other hand, the control group showed a significant loss in the spine BMD (2.26%). In another study carried out in men and women aged 60–80 years who completed 12 months of intervention, total-body BMD and BMC did not change in the active group after 6 months of gymnasium-based training, but was decreased by 0.9% and 1.5%, respectively, in the control group. Similar results were found at the end of the training programme.[44]

The following studies found that BMD could be increased or at least maintained at different sites after strength-training programmes. Nevertheless, there is no research that finds that BMD is increased at all sites where this parameter is measured (table II).

Kerr et al.[41] examined the effect on BMD in postmenopausal women of a 2-year exercise intervention and calcium supplement, showing significant effects of the strength programme at the total (+0.9%) and intertrochanter hip site (+1.1%), while there was no difference between the groups at the forearm, lumbar spine or whole-body sites. However, a 9-month strength-training programme led to an increase in lumbar BMD in the weight-trained older women (1.6%), whereas no significant weight-training effect was detected at femoral neck or distal wrist site.[34]

As in previous studies, Nelson et al.[36] demonstrated that 1 year of high-intensity strength training was able to enhance BMD by 1% at the femoral neck and lumbar spine in postmenopausal women, whereas in the control group women lost 2.5% and 1.8% at these sites, respectively. Moreover, the strength-trained women had a 14% improvement in dynamic balance, whereas the control group showed a decline in this parameter, which is very important in relation to falls and osteoporotic fractures.

Moreover, there are few studies that did not find extra benefits from short-term strength exercise programmes in the radius, lumbar spine, femoral neck or whole-body bone mass, showing a similar maintenance[38,39,42] or loss over the duration of the training period to the control group.

Only a few studies have evaluated, separately, the effects of strength training on bone mass in elderly men. The best results for bone mass were found after a 16-week strength-training programme in sedentary men.[35] In this study, BMD increased significantly at the femoral neck by 3.8% and at the lumbar spine by 2.0%. Whiteford et al.[47] showed that 12 months of once-a-week strength training resulted in similar gains of BMD in trochanter and total hip to an active control group and no changes were found in whole-body, lumbar spine and femoral neck BMD after the intervention.

In order to investigate which strength training regimen produced the best improvements in bone parameters, Kerr et al.[37] examined the effects of a 1-year progressive strength-training programme on the bone mass of postmenopausal women. Participants were divided into two training groups; a strength-trained group or an endurance-force group and a control group. The bone mass increase with the strength regimen was significantly greater at the trochanteric and intertrochanteric hip site, at Ward's triangle, and at the ultradistal radial site compared with the control group, while there was no significant increase in BMD with the endurance regimen except at the radius midsite. These results showed that postmenopausal bone mass can be significantly increased by a strength regimen with high-load low repetitions but not by an endurance regimen with low-load high repetitions. Therefore, the peak load seems to be more important than the number of repetitions (always over a threshold) in increasing bone mass in early postmenopausal women.

Although most of the studies that explored the impact of this kind of training programme on bone mass use DXA scanners to measure bone mass, some researchers also include pQCT in their methodology. In a study carried out by Adami et al.,[40] the overall density of the forearm rose 1.8% despite a significant decrease in the density of the trabecular component. Similarly, several years later, Liu-Ambrose et al.[43] showed a significant increase in cortical bone density at the shaft region of both the tibia and the radius in older women following 25 weeks of exercise intervention. None of the DXA measurements significantly changed at the end of the interventions in either study.

Therefore, as previously observed, strength exercise seems to be a powerful stimulus to improvement and maintenance of bone mass during the ageing process. Whereas benefits for the femoral neck, lumbar spine and radius have been reported, whole-body BMD seems not to be affected by this kind of training programme, since none of the studies showed increments in this parameter. Moreover, although DXA is the most widely used bone densitometric technique[48] in clinical diagnosis and research studies, the capability of pQCT to assess bone geometry may be advantageous in evaluating the effects of training on bone health.

3.3 Multi-Component Training

In order to test whether the combination of several types of exercise in a training programme could be more effective in improving BMC and BMD in elderly population, several authors carried out some research (table III).

Table III

The greatest improvements using a multi-component exercise training programme were found by Kemmler et al.[62] and Kukuljan et al.[61] Kemmler et al.[62] reported that, compared with a general wellness programme, 18 months of exercise intervention significantly improved BMD at the lumbar spine and femoral neck. Kukuljan et al.[61] showed that a 12-month multi-component training programme of strength and impact exercises led to and increase from

1.6% to 2.1% of BMD at the lumbar spine, femoral neck, trochanter and total hip in community-dwelling older men.

Other studies of combined training also found improvements to a lesser extent. In physically frail elderly women, the different effects of a combined strength- and aerobic-training programme with a flexibility control group were tested.[53] Both groups were added to ongoing hormone replacement therapy**((Author: please clarify what type of replacement therapy. 'hormone replacement therapy'?))**. After 9 months of training, there were larger increases in BMD at the lumbar spine among people performing the combined training programme compared with those of the flexibility programme group (3.5% vs 1.5%), with a trend for larger increases in total-body BMD (1.5% vs 0.2%). Nevertheless, there were no significant between-group differences in hip BMD. In the same way, Tolomio et al.[59] showed that a 20-week exercise programme with aerobic, balance and strength exercises was able to improve all bone parameters assessed by phalangeal quantitative osteosonography in osteopenic and osteoporotic postmenopausal women. Similarly, another study carried out by the same group found that an 11-month-long specific multi-component exercise programme 3 times per week (one water exercise session), was able to improve the femoral neck T-score in the same specific population.[63] Welsh and Rutherford[50] indicated that 1 year of high-impact aerobic exercise classes (including free weights and multigym) was able to bring about an improvement of 2.2% in trochanter BMD and also to offset the decline of bone mass in the femoral neck and whole body. The effect of long-term impact exercise on bone mass at various skeletal sites in elderly women with low BMD was tested by Korpelainen et al.[57] In this study, the exercise programme consisted of jumping and balance exercise 3 times per week during 6 months per year. After a period of 30 months, no change occurred within the exercise group at neck or trochanter, while a decrease of bone mass was found at these sites within the control group. Moreover, a significant decrease in BMC occurred at the trochanter within both groups, the loss being greater in the control group. Exercise did not have any significant effect on the bone at the calcaneus, distal or ultradistal radius, where values decreased similarly in both groups. Another study carried out by Bravo et al.[51] in osteopenic women showed that a programme of 12-months duration combining walking, dancing, stepping and strength exercises was able to maintain BMD at the lumbar spine and femoral neck, while a significant decrease occurred within the control group. Karinkanta et al.[58] showed that combined resistance-balance-jumping training was not enough to enhance bone mass in elderly women, but trained women had the tibial shaft structure weakened 2% less than those in the control group. Finally, the most recent study found in this area disclosed that multi-component training with moderate-intensity weight-bearing exercise can create significant bone adaptation over an 8-month period in community-dwelling older women through an increment of BMD at the femoral neck.[64]

However, other studies carried out in both sexes have found no effect on bone mass from the combined training programmes, showing that BMD at different sites is maintained[52,54,55] or reduced[56] in the same way for those who did not take part in the exercise programmes.

As the commonly-found attempts to lose weight among older adults may have adverse consequences in bone tissue, several authors have contrasted the impact of a multi-component exercise programme plus diet on bone mass in both sexes. Svendsen et al.[49] carried out a study with overweight postmenopausal women who were assigned to three groups; diet only, diet plus exercise and control. After 12 weeks of intervention, the lumbar spine BMD decreased in the diet plus exercise group and the whole-body BMD tended to decrease in the intervention groups compared with controls, whereas no change was found at the forearm. Several years later, Villareal et al.[60] tested the effect of 52 weeks of diet and combined exercise therapy in frail, obese older men and women. They observed greater decreases in hip BMD in the diet plus exercise group than in the controls, whereas no differences between groups were detected in lumbar spine or whole-body BMD.

As mentioned above in section 3.3**((Author: please indicate the section number))**, the large methodological differences between studies hinder a real comparison between them, and therefore, it is difficult to establish the ‘posology’ of the treatment to obtain the best effect through this kind of training programme.

It seems clear that the initial level of BMD is a notable factor in determining the results of the training programme. Lower baseline levels of bone mass may be related with higher benefits through exercise and, therefore, multi-component training may be considered as one of the main non-pharmaceutical measures that should be promoted in older subjects, especially osteopenic and osteoporotic women, in a preventative approach for 'bone health'.

This research shows that combinations of different exercise programmes are able to improve or at least to prevent bone decline among postmenopausal women. Nevertheless, men seem to be less susceptible to changes in bone mass, probably attributable to their higher baseline levels of BMD or even because they need exercise stimulus of higher intensity; however, as studies in men are less extensive, more research is needed to discover the real effects of this kind of training in this sex.

3.4 Whole-Body Vibration

Whole-body vibration (WBV) is a new type of exercise intervention that has been suggested, to assist in the prevention of bone fractures and osteoporosis (table IV). WBV training uses high-frequency mechanical stimuli, which are generated by a vibrating platform and transmitted through the body where they load the bone and stimulate sensory receptors. Skeletal responses to WBV are reported to be similar to that of specific training activating mechanotransduction in bone and stimulating osteogenesis.[75,76]

Table IV

To our knowledge, there is only one study that has found negative effects of WBV on bone mass among older women. In this study, Fjeldstad et al.[71] showed that 8 months of WBV plus strength training leads to a reduction of whole-body BMC, whereas the bone mass is maintained in the control group. Another study showed no changes in bone characteristics following a 6-month period of WBV intervention among postmenopausal women,[65] and yet another found that the addition of WBV to alendronate did not enhance the increase of BMD in elderly women.[68] On the other hand, some studies have reported positive findings, suggesting that WBV may represent an effective non-pharmacological intervention for preventing a decline in BMD, or for increasing or maintaining BMD in aged populations.[66,67,69,70,72-74]

One of the first studies carried out found benefits for bone mass at the femoral neck and spine in postmenopausal women who followed a WBV training programme.[66] After 1 year, placebo subjects lost 2.1% of BMD in the femoral neck and 1.6% in the spine, whereas treatment was associated with a gain of 0.04% and 0.1% (nonsignificant). The results became statistically significant at the spine of lighter women (<65 kg), who were in the highest quartile of compliance, explaining that adherence and body weight may influence the response to the WBV intervention.

In order to contrast the effect of WBV training and strength training, Verschueren et al.[67] performed a 24-week study in postmenopausal women. They found that WBV increased BMD of the hip significantly (0.9%); however, no changes in hip BMD were observed in women participating in strength training or age-matched controls. Two years later, it was reported that after 8 months of WBV in postmenopausal women, the BMD at the femoral neck of the trained group was increased by 4.3% compared with the walking group. Comparison of the changes in BMD at other sites on the hip showed a trend for higher effectiveness of the vibratory exercise, but the difference did not reach statistical significance. In contrast, BMD at the lumbar spine was unaltered in both groups. Moreover, the WBV group showed improved balance (29%), while the walking group did not.[69]

A further study showed that although the effects of conventional training (dancing aerobics, balance training, functional gymnastics and dynamic leg-strength) were not enhanced by WBV, in postmenopausal women, an identical exercise regimen with vibration during the leg-strengthening sequence could be positive to prevent fall frequency. Results showed that the number of falls was significantly lower in the vibration trained group (0.7 falls/person) than in the nonvibration trained group (0.96) and control group (1.5) after 18 months.[72]

The most recent research carried out in this area was the first to study the effect of WBV plus calcium and vitamin D supplements among institutionalized elderly women. The results showed that there was a significant increment of the total hip BMD, which was similar to that produced in the control group.[73]

Unlike other forms of exercise, where the duration of the training programme seems to be of great importance in order to achieve the desired effects on bone mass, the impact of WBV on BMD among older adults may be reached more quickly, according to the results found by Ruan et al.,[70] where 3- and 6-month periods of WBV intervention were enough to improve the lumbar spine and femoral neck BMD among osteoporotic women.

Recently, Von Stengel et al.[74] compared the effect of two different WBV protocols on BMD at the lumbar spine and femoral neck. The frequency and amplitude varied between interventions, resulting in similar accelerations. Otherwise, there were no differences between groups. A significant increase of 0.7% was observed in lumbar spine BMD in the group who trained on the rotational vibration devices, whereas the effect on the vertically vibrating group was borderline non-significant. No changes were found for femoral neck BMD in either group.

Although the WBV studies mentioned did not report any unexpected adverse outcome in terms of health, it has been proposed that individuals who have one of the following conditions should not partake in WBV training: kidney or bladder stones, arrhythmia, pregnancy, epilepsy, seizures, cancer, a pacemaker, untreated orthostatic hypotension, recent implants (joint/corneal/cochlear, etc.), recent surgery, recently placed intrauterine devices or pins, acute thrombosis or hernia, acute rheumatoid arthritis, serious cardiovascular disease, severe diabetes mellitus or migraines.[77]

In summary, WBV seems to be more effective than walking and similar to strength training for improving bone mass at different sites in postmenopausal women; nevertheless, more research is needed to prove that this is so in men as well. Moreover, the WBV training appears to have some extra benefits such as improved balance[69,78,79] and a decrease in the number of falls,[72] which are extremely important in preventing osteoporotic fractures. WBV training has also been promoted as a potentially safe, low-impact alternative to current methods, to combat bone deterioration in exercise-intolerant or mobility-limited individuals, without the risks associated with high-impact or strenuous exercise.[80]

In the current literature, training duration ranged from 6 to 18 months and training frequency from once per week to twice per day, the time spent training in a given day ranging from 4 to 20 minutes. With regard to the type of vibration exercise, some studies used devices that delivered a vertical form of vibration[66,67,71-74] and others provided a rotational form of vibration.[65,68,69,74] Vibration frequencies ranged from a relatively low 12.6 Hz to a maximum of

40 Hz and amplitude ranged from 0.7 mm to 12 mm. As reviewed previously,[77,80,81] it is clearly evident that treatment protocols varied considerably between the studies. Therefore, the differences found between studies could be partially mediated by the number of sessions per week, the frequency (Hz), the adherence, the kind of vibration machine used in the training programme, as well as exercises performed on the platform. Because of it being a relatively new concept, there is a lack of consistency and robustness in the methodology, indicating the inability of current research to establish an optimal vibration prescription for bone in older adults.[80] Further research should be conducted to explore the ideal dose of vibration, time course, frequency and posture required to elicit an optimal response.

With regard to the vibration devices, both vertical and rotational forms of vibration seem to be effective for bone mass increase in elderly women. The wide differences found between studies hinder a depth comparison and, therefore, it is difficult to draw a conclusion regarding which form of vibration has a more beneficial effect on bone mass. There is only one study where this issue is attended and it seems that rotational vibration may be more effective than vertical vibration;[74] however, this conclusion is premature given that the data is so limited.

3.5 Influence of Age and Sex in the Training Response and Effects of Detraining

Regarding to the differences in training response between men and women or young and old people, results are still controversial.

Bassey et al.[82] tested the effect of jumping exercise in premenopausal and postmenopausal women. In premenopausal women the exercise resulted in a significant increase of 2.8% in femoral BMD after 5 months, a change significantly greater than that found in their control group. However, in postmenopausal women there were no significant differences between the exercise and control groups after 12 months or after 18 months. It appears that premenopausal women respond positively to this brief high-impact exercise but postmenopausal women do not. On the contrary, other research found that there were no sex differences between men and women for any of the BMD regions and no age differences in the strength-training response, except for a trend between young and older subjects for the femoral neck. In this study, a 6-month-long, whole-body strength-training programme improved BMD of the femoral region in young, and in healthy older men and women, whereas no changes were found in spine and whole-body BMD.[83]

Finally, Maddalozzo et al.[84] compared the effects on bone mass in healthy older men and women of a moderate-intensity seated strength-training programme with a high-intensity standing free weight exercise programme. After 24 weeks, high-intensity training resulted in a gain in spine BMD in men (1.9%) but not in women, whereas moderate-intensity training produced no changes in either sex at this site. Increases were observed at the greater trochanter in men regardless of training intensity, but not in women at any hip site.

Although more research is needed to test the real influence of sex and age in response to training, it seems that women, especially the older ones, obtain less benefit after training programmes than do men and young women.

Regarding the effects of detraining on bone mass among older adults it is believed that continued exercise training is needed to maintain the gain in bone mass acquired through the different exercise programmes. Otherwise, BMD reverts toward baseline levels. Research has been carried out in order to test this hypothesis.

Studies carried out with postmenopausal women showed that BMC and BMD improvements after specific exercise programmes reverted toward basal levels with detraining. One research reported that weight-bearing exercise training was able to increase lumbar BMC by 5.2% above baseline after 9 months of training, whereas there was no change (−1.4%) in the control group. After 22 months of exercise, BMC was increased 6.1% in the training group. Nevertheless, after 13 months of decreased activity, bone mass remained 1.1% above baseline in the detraining group.[20] Similar results were found in postmenopausal women with osteoporosis, showing that 1 and 2 years of brisk walking and gymnastic training is enough to improve BMD at the lumbar site, but BMD reverted toward a level that was not significantly different from the control with 1 year of detraining.[85]

4. Discussion

4.1 Summary of Findings

The studies in older adults and elderly people indicate that bone-related variables can be increased, or at least the decline in bone mass during ageing attenuated, by following a training programme.

Walking modestly increases the load on the skeleton above gravity and, therefore, this type of exercise has proved to be less effective in preventing osteoporosis. This exercise intervention is not specifically designed to maximize loading forces to mechanically stress bone and induce changes in BMD, therefore, interventions that combine aerobic training with other forms of exercise that provide adequate skeletal loading may have greater benefits in improving bone mass among older adults.

As already observed, strength exercise seems to be a powerful stimulus for improving and maintaining bone mass during the ageing process. Upon review, the best improvements seem to be achieved through strength training of high-loading intensities with 3 sessions per week and 2–3 sets per session.[86] Although significant effects can be observed after 4 or 6 months in some locations of the body, the efficacy of the training programme is greater when it extends for at least 1 year. Multi-component exercise programmes of strength, aerobic, high-impact and/or weight-bearing training as well as WBV alone or in combination with exercise, may help to increase or at least prevent bone mass decline with ageing, especially in postmenopausal women.

Whereas benefits for the femoral neck, lumbar spine and radius have been reported after exercise interventions, whole-body bone mass seems to be less susceptible to change through exercise. The latter could be explained due to the fact that the benefit for mineral density is confined mainly to loaded bones that are directly involved in the exercise.[87]

Although DXA is the most widely used bone densitometric technique among the reported studies, the ability of pQCT to assess bone geometric properties may prove advantageous in evaluating the effects of training on bone health. In some of the studies examined, changes in bone mass and geometry became evident by pQCT even when DXA measurements were unremarkable. Although most of the bone sites measured with pQCT and DXA differed, pQCT measurements provided additional information about the effects of exercise on bone that could not be elucidated by DXA.[88]

Nevertheless, the large variations in the type, intensity and duration of the training programmes, the differences in age, sex and characteristics of the subjects (i.e. use of medications, baseline bone mass or coexistence of other pathologies) or the skeletal sites investigated and the lack of dietary supervision (i.e. calcium or vitamin D), are the main impediments to knowing which is the type of exercise that has greater benefits for bone mass.

4.2 Limitations

This review is limited by the relative lack of data specific to very old adults. Most of the controlled trials focus on older adults with an average age from 55 to 70, while studies among the very elderly population are not numerous. Therefore, no reliable conclusions as to the effect of exercise during senescence can be reported.

The majority of the longitudinal studies have been performed in women as a result of the critical importance of maintaining bone health and preventing osteoporosis in this population. Therefore, studies in men are fewer and more research is needed to know the real effects of exercise in this sex.

However, although most of the studies included in this review are randomized controlled trials, we also include a few non-randomized studies. The latter may condition the results because of a possible self-selection in group assignment of the participants, which is particularly important in exercise trials where individuals may be more or less predisposed to participate in exercise.

Finally, the relatively short term of the trials could sometimes mask a positive effect of exercise on bone.

5. Conclusions

Bone-related variables can be increased, or at least the common decline in bone mass during ageing attenuated, by following specific training programmes, especially in postmenopausal women.

Because skeletal responses to WBV are reported to be similar to that of specific training stimulating osteogenesis, and taking into account that the impact of WBV on BMD among older adults may be reached more quickly than in other forms of exercise, WBV training is a promising alternative to prevent bone fractures and osteoporosis. Because this type of exercise under prescription is potentially safe, it may be considered as a low-impact alternative to current methods for combating bone deterioration in exercise-intolerant or mobility-limited individuals, without the risks associated with high-impact or strenuous exercise.

Although DXA is the most widely used bone densitometric technique among the studies, the ability of pQCT to assess bone strength and geometric properties may prove advantageous in evaluating the effects of training on bone health. Because changes in bone mass and geometry became evident by pQCT even when DXA measurements were unremarkable, pQCT may provide new knowledge about the effects of exercise on bone that could not be elucidated by DXA.

The logical steps for future trials would thus be (i) the inclusion of long-term exercise training programmes that allow bone to adapt to the mechanical stress of training; (ii) the addition of pQCT measures to DXA scanners in randomized controlled trials; (iii) more trials among men, including older participants; (iv) more trials comparing the real influence of sex and age in training response; (v) the inclusion of diet parameters as covariates in the analysis; and (vi) research, which assesses the effect of detraining after exercise intervention.

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Fig. 1. Flow chart diagram of study selection.

Table I. Effects of aerobic training programmes on bone mass in older adults

Study (y)	No. of subjects[a] and sex	Age (y) and exercise frequency [a,b]	Exercises	Protocol time	Training intensity	Other	Bone measurement site(s)	Results
Dalsky et al.[20] (1988)	35 Women	55–70 3/wk	50–60 min weight-bearing exercise (walking, jogging, stair-climbing)	9 mo 22 mo	70–90% VO_{2max}	CS	LS BMC	9 mo, AT: ↑↑ 5.2% C: NC 22 mo, AT: ↑↑ 6.1%
Cavanaugh and Cann[21] (1988)	AT: 8 C: 9 Women	49–64 3/wk	15–40 min walking	52 wk	60–85% MHR		Spinal trabecular mineral density	AT: ↓↓ 5.6% C: ↓↓ 4.0%
Blumenthal et al.[22] (1991)	AT: 33 Y: 34 C: 34 Men/ women	60–83 AT: 3/wk Y: 2/wk	AT: 30 min bicycling, 15 min brisk walking/jogging and arm ergometry Y: yoga	16 wk	AT: 70% HRR	-	Distal radius BMD	NC
Nelson et al.[23] (1991)	AT: 18 C: 18 Women	60.2 ± 6.5 4/wk	Walking with loaded belts (3.1 kg) around waist	12 mo	75–80% MHR	CS	Spinal trabecular mineral density LS and FN BMD Radius shaft BMD	AT: ↑ 0.5% trabecular spine C: ↓ 7% trabecular spine NC LS, FN and radius shaft BMD
Martin and	AT1: 20	58.5 ± 7.3	Walking	12 mo	70–85% MHR	CS	LS BMD	NC

Notelovitz [24] (1993)	AT2: 16 C: 9 Women	3/wk	AT 1:30 min AT 2:45 min				Forearm	
Hatori et al.[25] (1993)	AT1: 12 AT2: 9 C: 12 Women	45–67 3/wk	30 min walking	7 mo	Speed that kept the exercise HR above (AT1) or below (AT2) the anaerobic threshold	-	LS BMD	AT1: ↑ 1.1% AT2: ↓ 1.0% C: ↓ 1.7%
Ebrahim et al.[26] (1997)	AT: 49 C: 48 Women	AT: 66.4 C: 68.1 3/wk	40 min brisk walking	12 mo 24 mo	Faster than usual walking but not so fast to be uncomfortable or to cause shortness of breath	Upper-limb fracture in the previous 2 y	LS and FN BMD	NC
Ryan et al.[27] (1998)	AT: 15 C: 15 Women	52–72 AT: 62 ± 6 C: 63 ± 6 3/wk	35 min walking or jogging	6 mo	From 50–60% to >70% VO_{2max}	Both groups followed a weight-loss programme through intervention	WB BMC and BMD LS and FN BMD	AT: ↓ 1.4% WB BMD NC WB BMC NC LS, FN, Ward's triangle, greater trochanter BMD C: ↓ 1.7% WB BMD and ↓ BMC ↓FN, Ward's triangle BMD

								NC LS, greater trochanter BMD
Chien et al.[28] (2000)	AT: 22 C: 21 Women	48–65 3/wk, 40 min	30 min walking, 10 min stepping using a 20 cm high bench	6 mo	70–85% VO_{2max}	Osteopenic	LS and FN BMD	AT: NC LS, ↑6.8% FN C: ↓2.3% LS, NC FN
Ay and Yurtkuran[29] (2003)	AT: 23 C: 23 Women	AT: 54.3 ± 6.1 C: 55.1 ± 5.3 3/wk	40 min walking, swaying and jumping in water	6 mo	10–13 RPE Borg scale	Sedentary Osteopenic CS	Calcaneus BUA and SOS T-score	AT: ↑↑ 19% BUA, ↑↑ 63% SOS T-score C: ↓ 11% BUA, NC SOS T-score
Yamazaki et al.[30] (2004)	AT: 27 C: 15 Women	49–75 AT: 64.2 ± 2.9 C: 65.7 ± 2.7 At least 4/wk	≥1 h walking	12 mo	50% VO_{2max}	Osteopenic/ osteoporotic CS	LS BMD	6 mo, NC 12 mo, AT: ↑ 1.7% C: ↓ 1.9%
Evans et al.[31] (2007)	SPI: 10 MPI: 12 SPI + AT: 11 MPI + AT: 10 Women	62 ± 5 3/wk	45 min treadmill, rowing, stair-climbing	9 mo	From 55–60% to 75–80% VO_{2peak}	Soy protein isolate or milk protein isolate supplementation	WB, LS, FN BMC and BMD	NC
Irwin et al.[32] (2009)	AT: 37 C: 38 Women	56 5/wk	Walking 150 min/wk	6 mo	From 50% to 60–80% MHR	Breast cancer survivors Physically inactive	WB BMC and BMD	NC
Silverman et al.[33] (2009)	AT: 46 C: 40 Women	50–70 AT: 60 C: 58 3/wk	45–60 min walking	6 mo	50–75% HRR	Overweight and obese Weight-loss programme	FN, LS BMC and BMD	AT: ↑↑ 2% FN BMD NC FN BMC, LS BMC, LS BMD C: NC FN BMC, FN

								BMD, LS BMC, LS BMD

a Exercise groups are stated where applicable.
b Data are presented in means, ranges or mean ± standard deviations.
AT = aerobic training subjects; **AT1/2 = AT subjects groups 1 and 2; BMC** = bone mineral content; **BMD** = bone mineral density; **BUA** = broadband ultrasound attenuation; **C** = control subjects; **CS** = supplemental calcium; **FN** = femoral neck; **HR** = heart rate; **HRR** = HR reserve; **LS** = lumbar spine; **MHR** = maximal heart rate; **MPI** = milk protein isolate; **NC** = no changes; **RPE** = rating of perceived exertion; **SOS** = speed of sound; **SPI** = soy protein isolate; **VO_{2max}** = maximal oxygen uptake; **VO_{2peak}** = peak oxygen uptake; **WB** = whole body; **Y** = yoga subjects; ↓ indicates significant decrease $p < 0.05$; ↑ indicates significant increase $p < 0.05$; ↓↓ indicates significant decrease $p < 0.01$; ↑↑ indicates significant increase $p < 0.01$.

Table II. Effects of strength training programmes on bone mass in older adults

Study (y)	No. of subjects and sex[a]	Age (y) and exercise frequency[a,b]	Exercises	Protocol time	Training intensity	Other	Bone measurement site(s)	Results
Pruitt et al.[34] (1992)	ST: 17 C: 10 Women	ST: 55.6 ± 0.9 C: 53.6 ± 1.0 3/wk	4 UE, 4 LE, 3 trunk	9 mo	UE: 10–12 RM LE: 10–15 RM	-	FN and LS BMD Forearm	NC FN or distal wrist ST: ↑ 1.6% LS C: ↓ 3.6% LS
Menkes et al.[35] (1993)	ST: 11 C: 7 Men	50–70 59 ± 2 3/wk	5 UE, 4 LE, 3 trunk	16 wk	5–15 RM	CS	WB, LS and FN BMD	ST: ↑ 3.8% FN, ↑ 2.0% LS, NC WB C: NC FN, LS, WB
Nelson et al.[36] (1994)	ST: 20 C: 19 Women	50–70 2/wk	5 weight-lifting 3 sets × 8 repetitions	12 mo	80% 1 RM	-	LS and FN BMD WB BMC	ST: ↑ 0.9% FN, ↑ 1.0% LS BMD, NC WB BMC C: ↓ 2.5% FN, ↓ 1.8% LS BMD, NC WB BMC

Kerr et al.[37] (1996)	ST: 28 AT: 28 Women	40–70 ST: 58.4 C: 55.7 3/wk	5 UE, 4 LE ST: 3 × 8 RM AT: 3 × 20 RM	12 mo	ST: 60% RM leg 40% RM arm AT: 20% RM leg 10% RM arm	-	H and forearm BMD	ST: ↑↑ 1.7% troch, ↑ 1.5% intertroch, ↑ 2.3% Ward's, ↑↑ 2.4% ultradistal radius AT: ↑↑ 0.1% radius midsite, NC H
Ryan et al.[38] (1998)	27 Women	62 ± 1 3/wk	5 UE, 4 LE, 1 trunk	16 wk	From 90% 3 RM to 1 set (UE) or 2 sets (LE) of 12–15 repetitions	-	Radius, LS, FN and WB BMD	NC
Taaffe et al.[39] (1999)	ST1:11 ST2:12 ST3:11 C:12 Men and Women	65–79 ST1: 68.5 ± 3.6 ST2: 69.4 ± 3.0 ST3: 71.0 ± 4.1 C: 68.9 ± 3.6 ST1: 1/wk ST2: 2/wk ST3: 3/wk	3 × 8 repetitions 3 LE, 3 UE, 1 back	24 wk	80% 1 RM	-	LS, H, mid-radius BMD WB BMC	NC
Adami et al.[40] (1999)	ST:118 C:116 Women	ST: 65 ± 6 C: 63 ± 7 2/wk + 30 min/day at home	70 min of exercises to maximize the stress of the wrist (press-up, flexion on the arms in a prone position, volleyball) + 10	6 mo		-	LS, FN, radius (DXA) BMD Proximal, ultradistal radius (pQCT)	NC LS, FN, radius (DXA) BMD, proximal radius BMC, BMD and ultradistal radius BMC (pQCT) ST: ↑↑ 3.2% cBMC,

			min lifting a 500-g weight with the forearm					↑ 1.8% total BMD, ↓ 3.4% tBMC, ↓↓ 2.6% tBMD ultradistal radius C: NC ultradistal radius
Kerr et al.[41] (2001)	ST: 42 AT: 42 C: 42 Women	ST: 60 ± 5 AT: 59 ± 5 C: 62 ± 6 3/wk 1 h/session	5 UE, 2 LE	24 mo	ST: 3 × 8 RM AT: 40 sec each station	CS	WB, LS, H and forearm BMD	ST: ↑↑ 1.1% intertroch, ↑ 0.9% H, NC WB, LS and forearm AT: NC C: NC
Bunout et al.[42] (2001)	ST: 16 ST + NS: 31 NS: 26 C: 25 Men and Women	≥70 ST: 74.4 ± 3.3 ST + NS: 73.7 ± 3.0 NS: 74.7 ± 3.7 C: 74.0 ± 3.7 2/wk 1 h/session	Chair stands Squats Step-ups in a stair Arm pull-ups	18 mo	Graded by a coach using RPEBorg scale	NS	WB BMD	↓ In all groups. Lower loss among ST + NS compared with the other groups
Liu-Ambrose et al.[43] (2004)	ST:32 Ag:34 C:32 Women	75–85 ST: 79.6 ± 2.1 Ag: 78.9 ± 2.8 C: 79.5 ± 3.2 2/wk 50 min/session	ST: from 2 × 10–15 to 2 × 6–8 repetitions UE, LE, trunk Ag: coordination, balance and psychomotor	25 wk	ST: from 50–60 to 75–85% 1 RM	Community-dwelling Osteopenic/osteoporotic	H, FN BMD cBMD tibia, radius	NC H, FN BMD ST: ↑ 1.4% cBMD 30% radius Ag: ↓ 0.4% cBMD 30% radius, ↑0.5% cBMD50% tibia C: ↓ 0.4% cBMD

			performance of LE C: stretching and relaxation techniques					50% tibia
Daly et al.[44] (2005)	ST: 6 C: 13 Men and women	60–80 3/wk	6 mo gymnasium: Dynamic exercise involving concentric and eccentric contractions 6 mo home: 6 UE, 1 LE, 1 trunk	12 mo (6 + 6)	6 mo gymnasium: 75–85% 1 RM 6 mo home: 60–80% 1 RM	Sedentary Overweight Type 2 diabetes mellitus (6 mo moderate loss weight + 6 mo normal diet)	WB, LS and FN BMC and BMD	0–6 mo: ST: NC WB, LS and FN BMC and BMD C: ↓ 1.5% WB BMC, ↓ 0.9% WB BMD, NC LS and FN BMC and BMD 6–12 mo: ST: NC WB, LS and FN BMC and BMD C: ↓↓ 0.6% WB BMD NC WB BMC, LS and FN BMC and BMD
Bocalini et al.[45] (2009)	ST: 15 C: 10 Women	57–75 3/wk 1 h/session	6 UE, 5 LE, 1 trunk	24 wk	50–85% 1 RM	-	LS and FN BMD	ST: NC C: ↓ 0.98% LS, ↓ 1.58% FN
De Matos et al.[46] (2009)	ST: 30 C: 29 Women	45–65 ST: 57.5 C: 56.6	At least 3 UE and 7 LE	12 mo	From 1 to 4 kg	Osteopenic or osteoporotic	LS and H BMD	ST: NC C: ↓ 2.26% LS, NC H BMD
Whiteford et al.[47]	ST:57 C:65	55–80 ST: 64 ± 6	ST:1 h 3 × 8 repetitions 5 UE	12 mo	ST: 8 RM		WB, LS, H BMD	NC WB, LS, FN ↑ Similar trochanter

(2010)	Men	C: 64 ± 6 ST: 1/wk C: 3/wk	and 4 LE C:30 min walking					and H

a Exercise groups are stated where applicable.
b Data are presented in means, ranges or mean ± standard deviations.
Ag = agility training subject; **AT** = aerobic training subjects; **BMC** = bone mineral content; **BMD** = bone mineral density; **C** = control subjects; **cBMC** = cortical BMC; **cBMD** = cortical BMD; **CS** = supplemental calcium; **FN** = femoral neck; **H** = hip; **LE** = lower extremities; **LS** = lumbar spine; **NC** = no changes; **RPE** = rating of perceived exertion; **NS** = nutritional supplementation; **RM** = repetition maximum; **ST** = strength training subjects; **ST1/2/3** = strength training groups 1, 2 and 3; **tBMC** = trabecular BMC; **tBMD** = trabecular BMD; **UE** = upper extremities; **WB** = whole body. ↓ indicates significant decrease $p < 0.05$; ↑ indicates significant increase $p < 0.05$; ↓↓ indicates significant decrease $p < 0.01$; ↑↑ indicates significant increase $p < 0.01$.

Table III. Effects of multi-component training programmes on bone mass in older adults

Study (y)	No. of subjects and sex[a]	Age (y) and exercise frequency [a,b]	Exercises	Protocol time	Training intensity	Other	Bone measurement site (s)	Results
Svendsen et al.[49] (1993)	MT + Diet: 48 Diet: 50 C: 20 Women	53.8 ± 2.5 3/wk	1–1.5 h: 30–55 min aerobic exercise (bicycling, stair walking, running), 8–10 UE, LE and trunk strength exercises (7–15 repetitions each one)	12 wk	Aerobic: >70% VO_{2max} Strength: 65% 1 RM	Overweight	WB, LS, forearm BMD	NC forearm MT + Diet: ↓ 1.9% WB, ↓ 2.4% LS Diet: ↓ 1.9% WB, ↓ 1.6% LS C: ↓ 1.2% WB, ↓ 0.4% LS
Welsh et al.[50]	MT: 15 C: 15	50–73 2–3/wk	1 h rhythmical work, jumps,	12 mo	60–75% MHR	-	WB, LS, FN BMD	MT: ↑ 2.2% trochanter, NC FN,

(1996)	Men and women		skipping 1 per wk: circuit with free weights, multigym and aerobic work					WB, LS C: ↓ 1.5%FN, ↓ 0.7 WB NC trochanter and LS
Bravo et al.[51] (1996)	MT: 61 C: 63 Women	50–70 MT: 59.6 ± 5.8 C: 59.9 ± 6.4 3/wk	25 min walking/dancing 15 min stepping up and down Muscular exercises (upper limbs, scapular waist, abdomen and back)	12 mo	60–70% HRR 12–15 RM	Osteopenic	LS and FN BMD	MT: NC C: ↓ 1.3% LS, NC FN
De Jong et al.[52] (2000)	MT: 36 C: 33 Men and women	>70 MT:76.5 ± 4.6 C:78.8 ± 6.7 2/wk	45 min muscle strength, coordination, flexibility, speed, aerobic exercises (balls, ropes, weights, elastic bands)	17 wk	Intensity 7 (of a 10-point RPE scale)	Frail elderly BMI ≤25 kg/m^2	WB BMD	NC
Villareal et al.[53] (2003)	MT: 14 C: 14 Women	75–87 3/wk	90–120 min of ST (5 UE, 3 LE exercises), ET (walking/cycling/rowing), balance, flexibility	9 mo	From 65 to 75–85% RM From 65–75 to 85–90% MHR	Physical frailty HRT	WB, LS and H BMD	MT: ↑ 1.5% WB, ↑ 3.5% LS, NC H C: NC WB, ↑ 1.5% LS, ↑ 1.2% H

Santa-Clara et al.[54] (2003)	MT: 13 AT: 13 C: 10 Men	45–68 MT: 55 ± 10 AT: 57 ± 11 C: 57 ± 11 3/wk	MT: ST 2 × 8–12 repetitions (6 UE, 2 LE), 2 × 20 abdominals, 2 × 10 low back exercises + 30 min walking AT: 50 min walking	12 mo	ST 40–50% 1 RM AT: 60–70% HRR	Coronary artery disease	WB, arms, legs BMD	NC
Binder et al.[55] (2004)	MT: 46 C: 44 Men and women	≥65 MT: 80 ± 7 C: 81 ± 8 3/wk	MT: phase 1 (3 mo): 22 exercises of flexibility, balance, coordination, movement speed, ST: 5–15 min of bike or treadmill Phase 2 (3 mo): shortened version of phase 1 + ST (3 × 8–12 repetitions). C: home exercise protocol including 9 exercises of phase 1	6 mo	ST: from 65 to 85–100% of the initial 1 RM	Hip fracture Frail community dwelling CS	WB and H BMD	NC
Stewart et al.[56] (2005)	MT: 51 (25 men/26	55–75 63.6 ± 5.7 3/wk	ST: 4 UE, 3 LE (2 × 10–15 repetitions), 45 min	6 mo	50% 1 RM 60–90% HR	Hypertension	WB, LS and FN BMD	Men: NC Women: MT: ↓ WB, ↓ greater

	women) C: 53 (26 men/27 women)		aerobic training (treadmill, cycle or stair stepper)					trochanter. NC LS and FN C: ↓ FN. NC WB, LS, greater trochanter
Korpelainen et al.[57] (2006)	MT: 68 C: 65 Women	MT: 72.9 ± 1.1 C: 72.8 ± 1.2 3/wk 6 mo per y	MT: 45 min jumping and balance exercises (walking, knee bends, leg lifts, heel rises and drops, dancing, stamping, stair climbing and stepping) 20 min/day exercise at home	30 mo		Osteopenic/osteoporotic	FN BMC and BMD Radius BMD Calcaneal BUA and SOS	MT: NC FN BMD ↓↓ 2.9% trochanter BMC, ↓↓ 3.8% distal radius and ↓↓ 3.1% ultradistal radius BMD, ↓ BUA and SOS C: ↓ 1.1 FN and ↓ 1.6% trochanter BMD, ↓↓ 7.7% trochanter BMC, ↓↓ 3.1% distal radius and ↓ 3.4% ultradistal radius BMD, ↓ BUA and SOS
Karinkanta et al.[58] (2007)	ST: 37 Bal: 37 MT: 38 C: 37 Women	70–78 ST: 72.7 Bal: 72.9 MT: 72.9 C: 72.0 3/wk	ST: 1 UE, 6 LE exercises Bal: static and dynamic balance, agility training, jumps and other impacts, changes of	12 mo	ST: from 50–60% to 75–80% 1 RM	Home dwelling	FN BMC Radius and tibia	Tibial shaft BSI ↓ 2% less in MT than in C

			direction exercises					
Tolomio et al.[59] (2008)	MT: 36 C: 28 Women	50–70 MT: 59.4 ± 4.3 C: 57.7 ± 4.7 3/wk	MT: ST + Bal 2 session × 60 min: walking, stretching, small jumps, isometric exercises, exercises with dumbbells, balls and therabands 1 session × 45 min: circuit training, 5 min each station (treadmill, arm ergometer, horizontal leg press, bike, lat-machine)	20 wk	Level 10–13 of RPE Borg Scale	Osteopenic/osteoporotic	Phalangeal quantitative osteonography: fingers of the non-dominant hand	MT: ↑ 21.6 m/s Ad-SOS, ↑ 5.1 UBPS, ↑ 0.3 T-score C: NC
Villareal et al.[60] (2008)	MT: 17 C: 10 Men and women	≥65 MT: 69.4 ± 4.6 C: 71.1 ± 5.1 3/wk	90 min: 15 min flexibility exercises, 30 ET (walking, step-ups, stair climbing, cycling), 30 min ST, 15 min balance	52 wk	Aerobic: from 75 to 90% PHR Strength: from 65 to 80% 1 RM	Frailty Obese Vitamin supplement MT: diet	WB, LS, H, FN BMD	MT: ↓↓ 2.4% H, ↓↓ 3.3% trochanter, ↓↓ 2.7% intertroch, NC FN, LS, WB C: NC H, trochanter, intertroch, FN, LS, WB
Kukuljan et al.[61] (2009)	MT: 46 C: 44 Men	50–79 MT:60.7 ± 7.1 C:59.9 ± 7.4	60–75 min ST from 3 × 15–20 to 2 × 8–12 repetitions (6	12 mo	From 50–60 to 80–85% 1 RM	Community dwelling	LS, H, FN BMD	MT: ↑ 1.7% FN, ↑↑ 2.1% LS, ↑↑ 1.2% H, ↑↑ 1.6 trochanter

		3/wk	LE, 2–3 trunk, 5 UE), muscle stabilization exercises, weight-bearing impact exercises for LE (90–180 impacts/session)					C: NC
Kemmler et al.[62] (2010)	MT: 115 C: 112 Women	≥65 MT: 68.9 ± 3.9 C: 69.2 ± 4.1 4/wk	2 supervised sessions: 60 min aerobic dance, balance, functional gymnastics, isometric strength LE and trunk, 2–3 UE exercises 2 home sessions: 20 min flexibility and ~10 ST exercises C: 1/wk coordination, balance, dances, AT, ST	18 mo	Aerobic dance: 70–85% MHR	Community dwelling CS	LS, FN BMD	MT: ↑↑ 1.8% LS, ↑↑ 1% FN C: NC LS, ↓↓ 1.1% FN
Tolomio et al.[63] (2010)	MT: 58 C: 67 Women	MT:62 ± 5 C:64 ± 5.3 3/wk: 2 land, 1	60 min ST, ET, balance and joint mobility exercises	11 mo		Osteopenic/Osteoporotic	FN, H, BMD and T-score SOS, UBPI and	MT: ↑ FN T-score. NC C: ↓ UBPI and T-

		water (2 home-based exercise periods)	(dumbbells, therabands, steps and balls)				T-score (osteosonography)	score (osteosonography). NC
Marques et al.[64] (2011)	MT: 30 C: 30 Women	60–95 69.9 ± 5.8 2/wk	60 min: 15 min moderate-high impact activities (marching in place, stepping, heel-drops), 10 min muscular aerobic exercises (UE and LE), 10 min balance, 10 min agility and coordination	8 mo		Community dwelling	WB, LS and FN BMD	MT: ↑↑ 2.8% FN, NC WB, and LS C: NC

a Exercise groups are stated where applicable.
b Data are presented in means, ranges or mean ± standard deviations.
Ad-SOS = amplitude-dependent speed of sound through the bone; **AT** = aerobic training subjects; **Bal** = balance training subjects; **BMC** = bone mineral content; **BMD** = bone mineral density; **BMI** = body mass index; **BSI** = bone strength index; **BUA** = broadband ultrasound attenuation; **C** = control subjects; **CS** = supplemental calcium; **FN** = femoral neck; **H** = hip; **HR** = heart rate; **HRR** = HR reserve; **HRT** = hormone replacement therapy; **LE** = lower extremities; **LS** = lumbar spine; **MHR** = maximal heart rate; **MT** = multi-component training subjects; **NC** = no changes; **PHR** = peak heart rate; **RM** = repetition maximum **RPE** = rating of perceived exertion; **SOS** = speed of sound; **ST** = strength training subjects; **UBPI** = ultrasound bone profile index; **UBPS** = ultrasound bone profile score; **UE** = upper extremities; **VO_{2max}** = maximum oxygen uptake; **WB** = whole body; ↓ = indicates significant decrease $p < 0.05$; ↑ = indicates significant increase $p < 0.05$; ↓↓ = indicates significant decrease $p < 0.01$; ↑↑ = indicates significant increase $p < 0.01$.

Table IV. Effects of whole body vibration protocols on bone mass in older adults

Study (y)	No. of subjects and sex[a]	Age (y) and exercise frequency[a,b]	Exercises	Protocol time	Training intensity	Other	Bone measurement site(s)	Results
Russo et al.[65] (2003)	WBV: 14 C: 15 Women	WBV: 60.7 ± 6.1 C: 61.4 ± 7.3 2/wk	WBV Stood Lateral oscillations Accelerations in the range of 0.1–10 g 3 × 2 min	6 mo	28 Hz	CS Vitamin D (3 mo)	Tibial bone density Volumetric total bone density tibial metaphysic Trabecular bone density Cortical bone density of tibial diaphysis	NC
Rubin et al.[66] (2004)	WBV: 28 C: 28 Women	47–64 WBV: 57.34 C: 57.33 7/wk	WBV: stand on it for 10 min, 2 session/day separated by a minimum 10 h	12 mo	30 Hz	-	LS, H and distal radius BMD	WBV: ↑ 0.18% LS among subjects <65 kg in the highest quartile of compliance, NC LS subjects >65 kg, H and radius C: ↓ 3.17% among subjects <65 kg in the highest quartile of compliance, NC LS subjects >65 kg, H

								and radius
Verschueren et al.[67] (2004)	WBV: 25 ST: 22 C: 23 Women	58–74 WBV: 64.6 ± 3.3 ST: 63.9 ± 3.8 C: 64.2 ± 3.1 3/wk	WBV: static and dynamic knee-extensor exercises on platform Amplitude: 1.7–2.5 mm ST: exercises for knee extensors	24 wk	WBV: 35–40 Hz ST: from 20 to 8 RM	-	H BMD	WBV: ↑ 0.93% ST: NC C: NC
Iwamoto et al.[68] (2005)	WBV: 25 C: 25 Women	55–88 1/wk	WBV: 4 min/session Amplitude: 0.7–4.2 mm	12 mo	20 Hz	Osteoporotic Alendronate	LS BMD	↑ similar in both groups
Gusi et al.[69] (2006)	WBV: 14 AT: 14 Women	66 3/wk	WBV: 6 sets of 1 min 1 min of resting period AT: 1 h walking	32 wk	WBV: 12.6 Hz	-	LS and FN BMD	WBV: ↑4.3% FN, NC LS AT: NC FN and LS
Ruan et al.[70] (2008)	WBV: 51 C: 43 Women	WBV: 61.2 ± 8.2 C: 63.7 ± 5.5 5/wk	WBV: 10 min/session Amplitude: 5 mm	6 mo	30 Hz	Osteoporotic	LS, FN BMD	WBV: ↑ 1.3% (3 mo), ↑↑ 4.3% (6 mo) LS BMD. NC (3 mo); ↑ 3.2% FN BMD C: NC (3 mo); ↓ 1.9% LS BMD. NC (3 mo), ↓ 1.7% FN BMD
Fjeldstad et al.[71]	ST:22 WBV +	60–75 ST: 63.9 ± 0.9	ST: 3 × 10 repetitions (3 UE, 5	8 mo	ST: 80% 1 RM WBV: from	-	WB BMC	ST: ↓ ~2.2% WBV + ST: ↓↓

(2009)	ST: 21 C: 12 Women	WBV + ST: 62.8 ± 1.1 C: 63.1 ± 1.4 3/wk	LE exercises) WBV + ST: ST with vibration stimulus while dynamic squats, shoulder press and wrist curls. Amplitude: 3 mm		15–30 to 40 Hz			~2.5% C: NC
Von Stengel et al.[72] (2011)((	151 WBV + MT MT C Women	65–76 68.5 ± 3.1 2/wk: 60 min/session + 2/wk (home) 20 min/session	MT: dancing aerobics, balance, functional gymnastics, dynamic leg strength WBV + MT: Comb + leg strength with vibration Amplitude: 1.7 mm	18 mo	70–80% MHR 25–35 Hz	CS Vitamin D	H and LS BMD	WBV + MT: ↑ 1.5% LS, NC H MT: ↑ 2.1% LS, NC H C: NC LS and H
Verschueren et al.[73] (2011)	WBV: 54 C: 57 Women	>70 3/wk	From 1 to 12 min/session WBV with static and dynamic exercises Amplitude: 1.6–2.2 g	6 mo	30–40 Hz	Institutionalized CS Vitamin D	H BMD	WBV: ↑↑ 0.75% C: ↑↑ 0.88%
Von Stengel et	WBV–R: 29	60–75 WBV-R:68 ± 4	7 × 90 sec WBV: 1- or 2-	12 mo	WBV-R: 12.5 Hz	CS Vitamin D	LS, FN BMD	NC FN WBV-R: ↑ 0.7% LS

al.[74] (2011)	WBV– V: 34 C: 33 Women	WBV-V:68 ± 4 C:68 ± 4 3/wk	legged squat Amplitude: 12 mm (WBV-R), 1.7 mm (WBV-V)	WBV-V: 35 Hz	WBV-V:NC LS C:NC LS

AT = aerobic training subjects; **BMC** = bone mineral content; **BMD** = bone mineral density; **C** = control subjects; **CS** = supplemental calcium; **FN** = femoral neck; **H** = hip; **LS** = lumbar spine; **M/W** = men/women; **MHR** = maximal heart rate; **MT** = multi-component training subjects; **NC** = no changes; **RM** = repetition maximum; **ST** = strength training subjects; **WB** = whole body; **WBV** = whole body vibration; **WBV-R** = rotationally whole body vibration; **WBV-V** = vertically whole body vibration; ↓ indicates significant decrease $p < 0.05$; ↑ indicates significant increase $p < 0.05$; ↓↓ indicates significant decrease $p < 0.01$; ↑↑ indicates significant increase $p < 0.01$.