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The Effects of Resistance Training on Bone Mineral Density in Postmenopausal Women – A Review of Current Evidence

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Abstract

Introduction and objective: Osteoporosis is a major public health problem among postmenopausal women, which is featured with decreased bone mineral density (BMD) and high fracture risk. The objectives of the present review is to address the impact of resistance exercise on BMD in postmenopausal women and to evaluate the potential mechanotransduction pathways needed for osteoporosis prevention.

Review methods: All data were collected from publicly available sources. This article's databases were accessed via PubMed, Scopus, and Web of Science.

A brief description of the state of knowledge: Recent research shows that estrogen is crucial in maintaining bone homeostasis, and its absence post-menopause accelerates bone resorption. Muscle mechanical loading via resistance training increases bone remodeling and improves BMD. Aerobic exercises along with resistance training together serve as a better approach in improving bone density and overall physical fitness. Specifically, in fracture-prone areas like the femoral neck, where high-intensity resistance training can have a significant effect on increase in BMD.

Summary: The findings of this paper indicate that resistance training is effective in preventing osteoporosis among postmenopausal women. Exercises with high resistance like deadlifts and squats improve BMD in the lumbar spine, hips and femoral neck. And, by adding resistance exercises as a part of an overall exercise regimen for postmenopausal women, we can be sure that they are noticeably maintaining their bone health and quality of life. More research is needed to unlock best training protocols and personalized significance.

Keywords: bone mineral density, BMD, strength training, resistance training, weight training, postmenopausal women, menopause, osteoporosis, bone health

Introduction

Reduced bone mineral density (BMD), leading to an increased risk of osteoporosis, is a common issue among postmenopausal women. Menopause is defined as at least 12 consecutive months of amenorrhoea not caused by physiological or pathological factors. Statistics show that most women spend more than one-third of their lives postmenopausal, making women's health during this period a global concern [1].

Osteoporosis has a profoundly detrimental effect on women's lives, significantly diminishing their quality of life. The primary issues related to postmenopausal osteoporosis in women include a reduction in both cortical and trabecular bone thickness, as well as a decrease in BMD, leading to an elevated risk of fractures [2,3]. These fractures can result in pain, disability, loss of functional independence, and even an increased risk of mortality. Osteoporosis currently affects millions of women globally. Osteoporotic fractures most commonly involve the vertebrae, and femoral neck fractures are among the most severe, with approximately one in three individuals dying within 12 months of sustaining a femoral neck fracture [4].

Osteoporosis is clinically defined as a deterioration in the quality and integrity of bone microstructure. According to the World Health Organization (WHO), the diagnosis of postmenopausal osteoporosis is based on a BMD T-score that is at least 2.5 standard deviations below the average for young women. This diagnosis is made using dual-energy X-ray absorptiometry (DXA), which evaluates bone mineral density at the hip, spine, and mid-radius [3,5].

The etiology of osteoporosis is multifactorial, with estrogen deficiency being the primary etiological factor in postmenopausal osteoporosis, leading to excessive bone resorption [5].

Objective

The aim of this paper is to examine the impact of strength training on bone mineral density (BMD) in postmenopausal women and to analyze the mechanisms of mechanotransduction that may play a key role in preventing postmenopausal osteoporosis. The paper will discuss current scientific research that highlights the benefits of regular physical activity, particularly strength training, in the context of bone health and preventing bone mass loss in postmenopausal women.

Methodology

For this narrative review, all data were collected from publicly available sources. Three bibliographic databases: PubMed, Scopus, and Web of Science were searched in March 2025. The combination of terms for record extraction was ["bone mineral density" OR "BMD"] AND ["strength training" OR "resistance training" OR "weight training"] AND ["postmenopausal women" OR "menopause"] AND ["osteoporosis" OR "bone health"]. Only studies in English were retrieved. No time restrictions were applied to the publication dates of the articles. Conference abstracts and book chapters were excluded. The reference lists of identified studies were also reviewed to find additional articles. Duplicate studies were removed using Rayyan – a web and mobile app for systematic reviews. Studies were screened based on the title and abstract and then selected for full-text review by the author.

Estrogen deficiency and its impact on bone resorption in postmenopausal women

Estrogen deficiency after menopause leads to increased osteoclast numbers and reduced osteoblast numbers, thereby triggering a state of net bone resorption and dramatically increasing loss of bone mass in postmenopausal women.

Estrogens exert their effects on bones via a direct effect on estrogen receptors on osteoblasts, osteoclasts, and osteocytes as well as an indirect effect by modulating cytokines and growth factors. Their action primarily comes from inhibiting increased resorption of bone by various cells in the skeletal system. Estrogens stimulate the production of osteoprotegerin (OPG), which acts as an inhibitor of receptor activator of nuclear factor kappa-B ligand (RANKL) receptors. Osteoprotegerin binds to RANKL, preventing its interaction with RANK receptors on osteoclasts and their precursors, which limits osteoclastogenesis and thereby reduces bone resorption [6, 7].

On the other hand, estrogens support the survival and function of osteoblasts (cells responsible for new bone synthesis) through the activation of the Wnt signaling pathway, which is crucial in bone formation. Estrogen deficiency disrupts these processes, favoring resorption over bone formation [6].

After menopause, when estrogen levels drop, there is an increase in the production of pro-inflammatory cytokines, such as interleukins (IL-1, IL-6), TNF-α, and RANKL. These are important cytokines in osteoclastogenesis, the process of differentiating osteoclast precursors into resorptive mature cells. The reduced levels of estrogen leads to increased progenitor osteoclast cells and an increase of RANKL production, and down regulation of OPG production by osteoblasts, leading to osteoclast recruitment and activation [8, 9, 10].

Consequently, osteoclast activity increases, resulting in enhanced resorption of bone. Moreover, the enhancement of RANKL expression and the decrease of OPG favors the recruitment of of a larger number of preosteoclasts and the extended lifespan of mature osteoclasts, which causes bone mass loss. This process is particularly evident in the trabecular bone, where osteoclast activity is greatest, resulting in significant bone mass loss [6, 10].

Furthermore, estrogens have the ability to regulate the production of transforming growth factor beta (TGF-β), which affects osteoclast apoptosis, limiting their number and activity. Estrogen deficiency results in reduced TGF-β production, contributing to the maintenance of a high level of active osteoclasts (figure 1) [7].

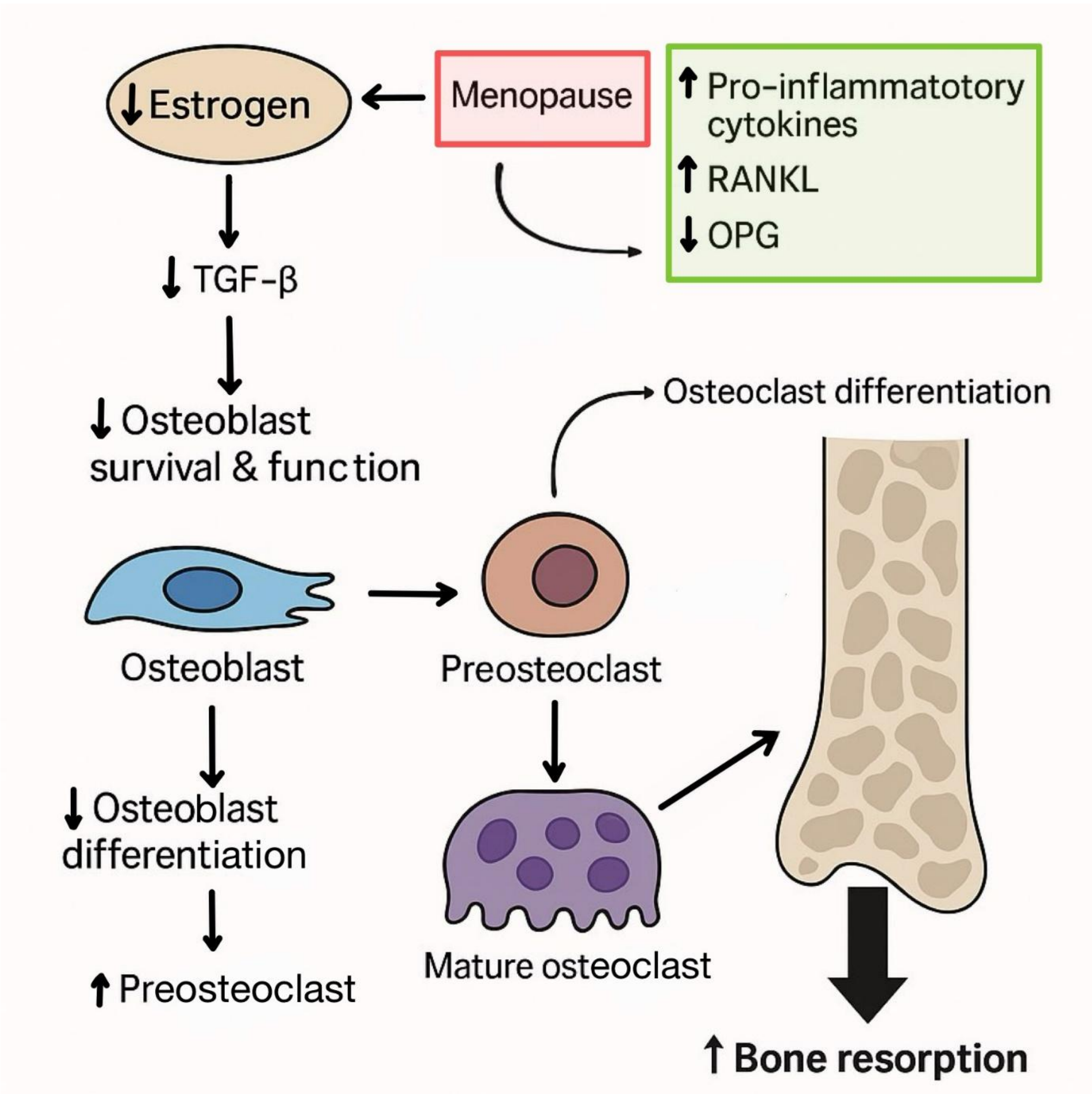

Figure 1. Effects of estrogen deficiency on bone metabolism in postmenopausal women. strogen deficiency leads to increased RANKL production and decreased OPG levels, which promote osteoclast formation and increase bone loss. Reduced OPG levels enable RANKL to bind to RANK receptors on osteoclasts, increasing their activity. In addition, estrogen deficiency impairs osteoblast function and Wnt signaling pathway activation, further leading to bone loss, especially trabecular bone. [7]

The role of physical activity in enhancing BMD after menopause

BMD testing is a non-invasive method commonly used to assess skeletal health, widely employed to evaluate fracture risk and bone fragility worldwide [11, 12]. During menopause, the average reduction in BMD is around 10%. In fact, up to half of women may experience even faster bone loss, with a 10%-20% reduction in BMD over a 5-6 year period during the menopausal transition [13].

Pharmacological treatment targeting BMD represents the first line of defense against osteoporosis. The most commonly used medications for osteoporosis include bisphosphonates and anti-resorptive drugs, such as denosumab or receptor activator of nuclear factor kappa-B ligand (RANKL) inhibitors [14]. However, these medications do not address other critical fracture risk factors, such as low muscle strength, power, and functional capacity. Moreover, the increasing issue of non-compliance with medical prescriptions [15,16], coupled with side effects caused by pharmaceuticals, has led to physical activity emerging as an effective, non-pharmacological tool for maintaining healthy bones [17]. Exercise training remains the only strategy to improve modifiable fracture risk factors, such as bone endurance, fall risk, and strength [18].

The role of mechanotransduction in bone adaptation to mechanical load

Bone is a plastic tissue that can modify its architecture and function upon microenvironmental changes. This mechanism is known as mechanotransduction, which enables the bone to translate exogenous mechanical signals into a biochemical response, which in turn modifies the cell's phenotype and function [19].

Bone adapts to alterations in mechanical load by adjusting its mass and structure to better resist future loads and prevent fractures [18]. Skeletal and mechanical loads caused by muscle forces significantly influence bone strength [20]. The effects of mechanical loading depend on the magnitude, duration, and speed of the applied load. Studies have shown that bone responds to dynamic, intermittent (not static) loading, loads of high magnitude applied quickly, loads applied in atypical or varied directions, or loading patterns with relatively few loading cycles (repetitions), as long as the appropriate intensity of load is achieved [18]. The load must be cyclic in order to stimulate new bone formation.

In the process of mechanotransduction, four stages can be distinguished: mechanosensing, biochemical coupling, signal transmission, and the response of the effector cell. Studies have demonstrated that mechanical loading causes bone deformation, which stretches bone cells (osteocytes) within and on the surface of the bone matrix. The movement of fluids within bone channels accompanying the deformation is a key factor in the mechanotransduction process. Stimulation of these cells to produce secondary messengers occurs due to stretching or fluid flow. However, there is a difference between the loads used in experimental studies, which are often much stronger than those experienced by living bone, leading to different results in experiments. Conversely, cyclic loading associated with extracellular fluid flow and the creation of streaming potentials in the bone has been shown to be more effective in stimulating new bone tissue formation in vivo [19].

The Impact of Strength Training on Bone Health in Postmenopausal Women

Strength training, as a non-pharmacological intervention, has shown promising results in mitigating bone loss by stimulating bone remodeling through mechanical loading [21]. Despite substantial evidence suggesting the benefits of resistance training in improving bone mineral density (BMD), there remains a need for further investigation into how different types of strength training influence bone health, particularly in postmenopausal women [22].

Exercises must involve direct or indirect loading of skeletal areas that are most prone to fractures, such as the hip, spine, and wrist. Sinaki, in a study of 65 postmenopausal women, demonstrated the long-term impact of strong back muscles in reducing vertebral fractures in women with estrogen deficiency. The difference in BMD, which was not significant between the back exercise group and the control group at the start of the study and after 2 years of observation, became significant after 10 years ($p = 0.0004$) [23]. This suggests that strong back muscles play a crucial role in stabilizing the spine, thereby reducing the risk of vertebral fractures in the long term.

In another study, Holubiac found a statistically significant effect of resistance training on lumbar spine BMD ($\Delta\% = 1.82\%$) in a group of 29 postmenopausal women with osteopenia/osteoporosis. The training protocol involved 6 repetitions at 70% 1RM (one-repetition maximum) and 6 repetitions at 50% 1RM within the same set [24]. Zehnacker emphasized that the effectiveness of strength training in improving BMD in areas such as the hips and spine is strongly related to training intensity. Significant effects require loads of 70-90% of 1RM for 8-10 repetitions in 2-3 sets, performed at least for 1 year, 3 times per week for 45-70 minutes per session [25].

Studies have shown that specific types of exercises, such as weighted squats, leg presses, and stair climbing with weighted vests, can contribute to increased BMD [25]. Moreover, Massini recognized resistance training as an effective intervention for increasing bone mineral density. The applied protocol, including 4-5 exercises for the upper and lower limb muscles, 2-3 sets per exercise, 8-12 repetitions at 70-90% 1RM for 12-52 weeks, also had a positive effect on BMD in the hip (0.64%) and spine (0.62%), although it did not affect the femoral neck (-0.22%) [26].

González-Gálvez confirmed the benefits of resistance training, which included improvements in maximal oxygen uptake ($SMD = 2.32$, $p < 0.001$), lower limb strength ($SMD = 4.70$, $p < 0.001$), and upper limb strength ($SMD = 7.42$, $p < 0.001$) in postmenopausal women. These studies demonstrated that regular resistance training significantly improves the quality of life of participants when performed 3 times a week for 60 minutes [27].

A key aspect of the positive impact of exercise on bone health is the need to exceed the normal loads experienced during daily activities and gradually increase the training stimulus [18]. Benedetti highlighted that the effectiveness of training depends on whether the applied force exceeds regular daily activity and enhances muscle strength [28]. The frequency of resistance training is also crucial. According to Englund, the positive effect of weight-bearing training on BMD is lost once physical activity ceases. In a study of 34 women aged 73-88, significant BMD loss was observed during a 5-year follow-up, supporting the idea that continuous physical activity is essential for maintaining bone density [29].

Kemmler also noted that the minimum effective dose of exercise for influencing BMD is at least two sessions per week. However, the frequency of exercise may prove more important than the intensity [30].

The first changes in BMD typically occur in the initial months of regular training. Lohman's study showed a BMD increase of 2.8% in the lumbar spine after 5 months, 2.3% after 12 months, and 1.9% after 18 months, compared to the control group [31].

The bone's response time to loading is usually slow, as the typical bone remodeling cycle lasts from 3 to 8 months. Studies suggest that training interventions should last at least 6 to 9 months to observe changes in bone structure, with 12 to 24 months being ideal to go beyond the normal bone remodeling process [18]. Bonaiuti observed that weight-bearing exercises contribute to increased BMD in the lumbar spine and hips in postmenopausal women, with the most significant effects visible only after the first two years of exercise [32].

In a study by Chang, it was found that the risk of osteoporosis was lower in postmenopausal women who exercised regularly compared to those who did not exercise or exercised irregularly. Regular exercise reduced the risk of osteoporosis (odds ratio OR 0.76, 95% CI 0.71–0.81) compared to women who did not exercise regularly. Incidental osteoporosis was observed in 10.5% of regular exercisers and 11.2% of non-exercisers [33].

Despite promising results, further research is needed on optimal training protocols to precisely determine which types of training are most effective in improving bone health in postmenopausal women. Existing studies suggest the need for further analysis of the intensity, duration, and frequency of training to better understand their impact on bone mineral density in this patient group [22].

Combined Resistance and Aerobic Training for Bone Health in Postmenopausal Women

In the available literature, there is evidence suggesting benefits from combining resistance training with other types of exercise, including aerobic training. Kim demonstrated that the type of physical training could be a key factor contributing to the improvement of bone health. In a study conducted on a population of Korean women, improvements in BMD in the lumbar spine, femoral neck, Ward's triangle, and trochanter were observed only when combining resistance training with aerobic training. However, both aerobic training and resistance training alone showed inconsistent results [34]. Additionally, Cheng confirms the benefits of combining resistance and aerobic training for bone health [35].

Filipović, in a study on a Serbian group of postmenopausal women with osteoporosis (n=96), showed improvement in functional status after a 12-week exercise program that included resistance training, balance exercises, and aerobic exercises. Significant improvements were noted in all observed measurements (Time Up and Go test (TUG), Sit To Stand test (STS), and one-leg stance test (OLST)) in the experimental group at both 4 and 12 weeks. The difference between the experimental and control groups was statistically significant for all functional outcomes at both observed periods ($P<0.001$ for all). The study also demonstrated that the training protocol reduced patients' fear of falling by improving their balance [3].

Rossi showed that combining resistance training with aerobic exercises halted the decline in BMD and even led to a slight, though statistically insignificant, increase in BMD, along with a slight decrease in body weight and an increase in muscle mass. A gain in lean body mass was observed in various body areas [36].

Zhao confirmed the hypothesis that combined exercise interventions are effective in preserving BMD in postmenopausal women (n=1061) in the lumbar spine, femoral neck, total hip, and whole body. Exercises integrating different physical activities significantly increased BMD in the lumbar spine (SMD, 0.170; 95% CI: 0.027, 0.313; $P = 0.019$), femoral neck (SMD, 0.177; 95% CI: 0.030, 0.324; $P = 0.018$), total hip (SMD, 0.198; 95% CI: 0.037, 0.359; $P = 0.016$), and whole body (SMD, 0.257; 95% CI: 0.053, 0.461; $P = 0.014$) BMD [37].

It is also important to consider the impact of different volumes of aerobic exercise on BMD in postmenopausal women. Gonzalo-Encabo compared the effects of moderate (150 min/week) and high doses (300 min/week) of aerobic exercise. The results showed that women performing more impact exercises per week had a significantly higher average bone mineral density level after 12 months compared to baseline (0.006 g/cm^2, 95% CI: 0.006-0.012; $P = 0.03$). A greater amount of exercise, especially impact exercises, led to a smaller decrease in total bone mineral density, which may persist after the intervention ends [17].

An important aspect is also the duration of the intervention and the combination of different types of training. This hypothesis is confirmed by a study conducted by Bravo, in which a group of 124 postmenopausal women performed weight-bearing exercises (walking, stepping up and down benches), aerobic dance, and flexibility exercises for 60 minutes, three times a week, for 12 months. After 12 months, it was found that combining exercises led to a significant increase in functional fitness, improvement in well-being, and perceived health in women with osteopenia compared to baseline. The exercise program effectively stabilized spinal BMD but did not affect femoral BMD. Additionally, a reduction in back pain was observed after 12 months [38].

A promising option is also high-speed strength training, involving rapid concentric muscle contractions, which can generate high bone loads. In a study conducted by Stengel (n=53), the effects of slow and fast resistance exercises on various osteodensitometric parameters were compared. After 12 months, significant differences were observed between the groups for BMD in the lumbar spine ($P < 0.05$) and the entire hip ($P < 0.05$). The group performing high-speed training maintained BMD in the spine (+0.7 ± 2.1%, not significant) and total hip (0.0 ± 1.7%, not significant), while the traditional strength training group showed a significant loss in both areas (spine: -0.9 ± 1.9%; $P < 0.05$; total hip: -1.2 ± 1.5%; $P < 0.01$) [39]. Haque demonstrated that high-velocity resistance exercise doses performed ≥2 sessions per week will bring the most skeletal benefits, and if the exercises are interrupted for more than 6 months, the achieved benefits may be lost. Combining high-speed strength training with regular sessions can therefore be particularly beneficial for maintaining bone health over time [40].

Combining resistance training with aerobic exercise provides significant benefits for bone health, especially in postmenopausal women. These exercises improve bone mineral density, balance, and functionality, while also reducing the risk of falls. Moreover, the duration of the intervention and the variety of training forms, such as high-speed strength training or impact exercises, contribute to maintaining BMD and overall quality of life improvement.

Discussion

Postmenopausal osteoporosis is a significant public health problem because of the increased risk for fracture and decreased quality of life in women who have the disease. A wealth of evidence has demonstrated an important role of estrogen deficiency in osteoporosis pathogenesis mainly due to interference with the coupling of bone resorption and formation. A decrease in estrogen levels following menopause leads to the activation of osteoclasts, with accelerated bone resorption, mainly involving trabecular bone.

A review of studies on the impact of resistance training on bone mineral density in postmenopausal women has shown that this type of physical activity has significant benefits in preventing osteoporosis. Osteoporosis represents a serious health problem in the elderly, characterized by low bone mass and bone fragility, leading to an increased risk of fractures. Estrogen deficiency causes acceleration of bone resorption and imbalance of regulation of skeletal system functions. Estrogens act on receptors in osteocytes, stimulating resorption and inhibiting new bone formation. Involving mechanical action like vigorous strength training, the strain from squats or deadlifts, induced an increase in bone mineral density in appropriate regions, such as the lumbar spine and hips.

The benefits of resistance training extend well beyond bone health: It strengthens muscles and improves balance, which can help lower the risk for falls the main contributor to fractures in this age cohort. Equally important is mechanotransduction, which enables bones to adapt to mechanical loads. When mechanical forces are applied to the skeleton, the osteocytes, which serve as the sensory cells of bone, activate biochemical signaling pathways that trigger the development of new bone tissue and prolongate it.

Combining strength training with aerobic exercise can help on many levels. Research shows that activity combining different types of exercise can lead to increased BMD and improved overall athletic performance. This type of combined approach not only increases bone density, but also has positive effects on the cardiovascular system and increases muscle size, further reducing the risk of osteoporotic fractures. Regularity of physical activity is key, as irregular exercise has been shown to have a poor effect on improving BMD.

The effectiveness of resistance training depends on several factors - intensity, duration and frequency. High-intensity training with a load of 70-90% of the maximum load for one repetition (1RM) for 8-10 repetitions, performed at least three times a week, is recommended. In order to maintain the progress in BMD achieved through exercise, the programme must be followed consistently. Furthermore, in order to achieve the greatest benefit and avoid injury, it is extremely important that training programmes are tailored to the individual's needs and condition.

However, despite the good evidence, more research needs to be done to improve training plans and learn more about how exactly resistance exercise helps the bones of postmenopausal women. Research should also look at how different types of training and programmes can be altered according to a person's health needs to get the best results.

Conclusions

Concisely, resistance training is an important factor in postmenopausal women with osteoporosis whereas it is a non-pharmacological intervention to address BMD and fracture risk. The good news is that, by combining resistance exercise with a total exercise programme, postmenopausal women can create an exercise plan that has a large impact on both bone health and quality of life. Additionally, more research is needed to optimise exercise protocols and individualise those protocols with a specific health range.

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Author's contribution:

Conceptualisation: Alicja Tabian
Methodology: Alicja Tabian
Software: Alicja Tabian
Check: Alicja Tabian
Formal analysis: Alicja Tabian
Investigation: Alicja Tabian
Resources: Alicja Tabian
Data curation: Alicja Tabian
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