Curr Treat Options in Rheum (2018) 4:268–278
DOI 10.1007/s40674-018-0103-5

Osteoporosis (A Lau, Section Editor)

Physical Activity for Fall and Fracture Prevention

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Published online: 21 June 2018

This article is part of the Topical Collection on *Osteoporosis*

Keywords Osteoporosis · Fall prevention · Fracture · Exercise · Physical activity

Abstract

Purpose of review The aim of this review is to provide healthcare professionals with evidence-based physical activity recommendations, and tips for implementing them in practice.
Recent findings Individuals with osteoporosis should engage in a multicomponent exercise program that includes twice-weekly resistance training, balance exercises, and 150 min per week of moderate to vigorous intensity aerobic physical activity. There is strong evidence that exercise programs that include challenging balance exercises and include at least 3 h a week of exercise can prevent falls. Resistance training is encouraged to increase muscle strength and prevent bone loss.
Summary Because of the strong evidence supporting challenging balance exercises for fall prevention, and multicomponent exercise programs that include resistance training for prevention of bone loss, aerobic physical activity should not be recommended to the exclusion of resistance and balance exercises. Examples and tips are provided to support exercise counseling.

Introduction

Osteoporosis is a bone disease characterized by low bone mass and microarchitectural deterioration of bone tissue, which leads to bone fragility and an increased risk of fractures. Fractures occur when the load applied to bone is greater than bone strength, and are often the result of a fall (Fig. 1) [1•]. Risk factors for fracture include increasing age, female sex, previous fractures, parental history of hip fracture, smoking, and use of

glucocorticoids [2]. Fractures represent an important cause of morbidity and mortality: there is a five- to eightfold increased risk of death in the first 3 months after hip fractures [3] and 16% of people die in the 5 years following a vertebral fracture [4]. Osteoporosis Canada (2017) [5] estimates that over 80% of all fractures in people ≥ 50 years old are caused by osteoporosis. Furthermore, 9.9 million Americans and 1.5 million Canadians have been diagnosed with osteoporosis, while one in two Caucasian women and one in five Caucasian men will experience an osteoporosis-related fracture during their life [6]. Importantly, many people with osteoporosis live with a fear of fractures, or with pain and impairments in physical function from prior fractures, which can result in activity limitations and restrictions in participation in life roles [7]. Clinical practice guidelines for the management of osteoporosis recommend exercise as an adjunct therapy for fracture prevention. Certain types of exercise may prevent bone loss in postmenopausal women [8••].The aim of this narrative review is to provide healthcare professionals with evidence-based physical activity recommendations for individuals with osteoporosis, and tips to put them into practice (Fig. 1).

Physical activity principles

Although the terms "exercise" and "physical activity" have distinct definitions, they are often used interchangeably. Physical activity can be defined as any movements of the body produced by skeletal muscles and leading to energy expenditure (including household chores or activities of leisure), while exercise is a planned, structured, repeated, and purposive type of physical activity with the intent of improving or maintaining physical fitness [9•]. An exercise or physical activity recommendation is usually prescribed using the FITT (frequency, intensity, time, and type) principle (Table 1), whose combination determines the total volume of training. An exercise principle that is very relevant to health care providers is *specificity*, where the adaptations are specific

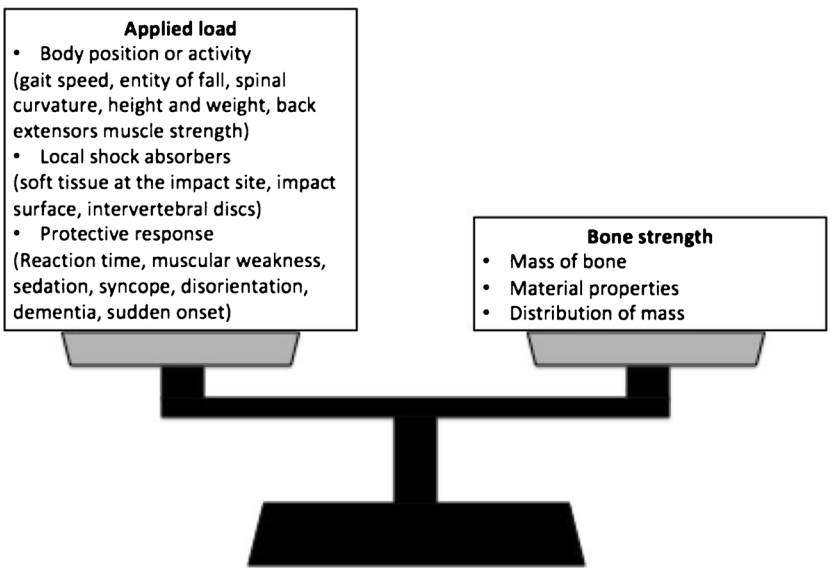

Figure 1. Balance between loads applied to bone and bone strength, with the factors affecting these two parameters. Fractures occur when the load applied to bone exceeds bone strength (modified from [1•]). Reprinted by permission from Springer: Osteoporosis International [1•]

Table 1. Definition of the FITT principle components [11]

Frequency	Number of times an exercise routine or physical activity is performed per week or per day
Intensity	Objectively measured work (oxygen uptake, heart rate, lactate threshold, caloric expenditure, power output, and percent of maximum strength/endurance) or subjectively reported (personal statement or Borg scale for the perceived exertion) level of effort performed
Time	Amount of time (continuous or intermittent) spent performing exercise or physical activity daily, or per bout
Type	The type or mode of exercise or physical activity performed

to the type of training. Therefore, the most effective way to improve balance is to apply balance challenges, as is supported by meta-regression analyses of exercise characteristics in clinical trials [10]. Another important principle is *overload*: muscle respond to a stimulus that is greater than what it is accustomed to [11]. Physical activity recommendations for individuals with osteoporosis have been established that highlight the minimum frequency, intensity, and time (duration) for several types of exercise or physical activity [12••]. Further, the recommendations outline how to ensure safe performance of exercise, as well as physical activities of daily living and leisure, including "spine sparing" strategies [13•]. Individuals with vertebral fractures should consult with a physician, and ideally an exercise physiologist or physical therapist with training related to osteoporosis (e.g., BoneFit™) before initiating an exercise program [12••]. The following sections summarize evidence and recommendations for the following types of physical activity or exercise: balance and resistance training, aerobic physical activity, and spine sparing strategies. We present the ideal frequency, intensity, time, and type based on evidence. It is not expected that all of these recommendations be implemented at once. Rather, the clinician is encouraged to prioritize realistic therapeutic goals and exercise next steps in collaboration with the patient. See case studies for examples (Table 1).

Balance training

There is strong evidence that exercise, particularly exercises that involve a high challenge to balance, can prevent falls in older adults. A 2017 meta-regression evaluating the most effective types of exercise for fall prevention reveals that exercise programs that include at least 3 h a week of exercise, and include exercises with a high challenge to balance can reduce falls by 39% among community-dwelling older people, even when trials of higher risk populations are included [10]. What is a high challenge to balance? It was defined as (a) moving the center of mass, (b) reducing the base of support, and (c) reducing upper limb contact with support objects [14]. Accordingly, a meta-analysis of studies including Tai Chi or combined programs consisting in gait, balance, and functional training showed a significant reduction of the rate of falls [15]. The American College of Sport Medicine [16] recommends activities with increasingly difficult postures with gradual reduction of the base of support, e.g., stand with feet together → semi-tandem stance → tandem stance → standing on one foot. One can add progressive reduction of sensory inputs (e.g., standing with eyes closed) or dynamic movements perturbing the center of gravity (e.g.,

tandem walk, lunges or half lunges, circle turns, and heel or toe walking) [16]. Others have recommended three-dimensional movements through all three spatial planes or dimensions, such as dance or Tai Chi [11], because of their challenge to stability thus stimulating postural muscles involved in maintaining body balance [17]. Furthermore, a network meta-analysis revealed that a multidisciplinary approach involving exercise, vision assessments, environmental modifications, and adequate nutrition may reduce injurious falls [18]. Having a support object nearby, and appropriate footwear is important when starting a balance training program. Balance training can include reducing the use of upper limb support on an assistive device or support object. Balance exercises should be tailored to be sufficient to challenge balance but not too high a challenge, thus increasing the risk of fall. The balance training recommendations are summarized in Table 2. *Clock Yourself* (http://clockyourself.com.au/) is an easy-to-use app that progresses the user through progressively complex exercises, training reactive stepping, and thinking on one's feet (Table 2).

Resistance training

Resistance training can be described as performing muscle contractions against a resistance, which can include working against gravity or an external resistance (e.g., free weight), and usually working to muscular fatigue to bring about a training effect in the muscular system [16]. There are several lines of evidence that progressive resistance training can increase muscle strength in older adults [19–21], including a Cochrane meta-analysis [21] (73 trials, $n = 3059$, standardized mean difference 0.84; 95%CI, 0.67–1.00). Further, a group exercise program that included progressive resistance training prevented incident mobility disability among at-risk older adults in a multicenter trial [22] (HR 0.82 [95%CI, 0.69–0.98]) and two meta-analyses revealed positive effects on spine BMD brought about by high-intensity resistance training [23] or on both spine and hip BMD after combined training programs [24]. A Cochrane review reported in subgroup analyses that resistance training or combined resistance and aerobic training can increase spine (24 trials, $n = 1441$, standardized mean difference 0.85; 95%CI, 0.62 to 1.07) and hip (13 trials, $n = 863$, standardized mean difference 0.41; 95% CI, – 0.64 to 1.45) BMD compared to a control group in post-menopausal women aged 45–70 years; interventions ranged in

Table 2. Balance exercise recommendations for fall prevention

Frequency	Intensity	Time (duration)	Type
Daily	Challenging enough that it requires concentration, but not so challenging that fall risk is high.	Entire exercise program (e.g., resistance, aerobic, and balance) of > 3 h a week most effective for fall prevention	Postures with reduced base of support (e.g., tandem stance); dynamic movement patterns perturbing center of gravity (e.g., heel toe walking, lunges, and reactive stepping); reduction of sensory input (e.g., standing with eye closed)

duration, with the majority being 12 months or longer [8••]. Furthermore, given the small to moderate benefits on lumbar spine and femoral neck BMD brought about by ground and/or joint reaction force exercises, a meta-analysis reveals the importance of participation in regular exercise programs for men, especially those at risk of osteoporosis [25]. Exercise should include load-bearing activities at moderate to high intensity, target sites at a greater risk of fracture (such as the hip, wrist, lower back, and femur) and be long-term and progressive [26]. Indeed, a recent randomized controlled trial revealed positive effects of high-intensity resistance training on bone strength in post-menopausal women with low bone mass [27]. Multi-joint exercises (such as squat, push-up, and pull-up) targeting the major muscle groups should be prioritized. They can be performed by means of resistance bands, cables, free weights, or using body weight as resistance. Intensity is usually prescribed as number of "repetitions maximum," i.e., three repetitions maximum is an exercise difficulty where you can only perform three repetitions. Moderate intensity, or 8–12 repetitions maximum is recommended for older adults or individuals with osteoporosis. However, progression to higher intensity (e.g., less than six repetitions maximum) may be appropriate for some individuals, with supervision by an experienced exercise physiologist with strength and conditioning and osteoporosis training, with consideration for the potential risks and benefits. Spine sparing strategies are strongly encouraged [12••] (see section). The resistance training recommendations are summarized in Table 3.

Aerobic physical activity

The physical activity guidelines for older adults provided by the Canadian Society for Exercise Physiology, American College of Sports Medicine, and Centers for Disease Control and Prevention recommend at least 150 min of moderate to vigorous intensity aerobic physical activity per week, in bouts of 10 min or more [28–30]. Aerobic physical activities, such as cycling or walking, should be encouraged because they can reduce the risk of cardiovascular disease, among many other health benefits. Activities that involve weight bearing may prevent bone loss; however, they may need to be of higher impact to have an effect on hip BMD [31]. A 2011 meta-analysis reported that, even though walking and Tai Chi may improve BMD at the spine and wrist, exercise programs that are higher impact or combine aerobic physical activity with resistance training may be more effective at the hip [8••]. Indeed, although many healthcare professionals often recommend walking for people living with OP

Table 3. Resistance training recommendations for people with osteoporosis

Frequency	Intensity	Time (duration)	Type
Each muscle group challenged 2–3 days/week	8–12 repetitions maximum	2–3 sets per exercise (can increase sets over time)	Multi-joint resistance training exercises, targeting major muscle groups, using weights, machines, elastic bands, dumbbells, and kettlebells

[32], more recent physical activity recommendations recommend that aerobic physical activity should not be performed to the exclusion of resistance and balance training [12••]. Health care providers should recommend multicomponent (e.g., strength, balance, and aerobic training) because the highest level of evidence we have related to fracture prevention pertains to the effect of exercise on falls, and studies of exercise and BMD appear to support multicomponent programs that include resistance and weight-bearing exercise [8••, 10]. In individuals who are high risk for fracture, the risks of high impact activities may outweigh the benefits. In moderate risk individuals, impact activities can be progressed at the discretion of an experienced therapist, with careful consideration of fracture risk factors, current health, and other factors [13•]. Further, in individuals at high risk of fracture, the risk of vigorous intensity activities may outweigh the benefits. The aerobic physical activity recommendations are summarized in Table 4.

Spine sparing strategies for exercise and physical activities of leisure and daily living

Biomechanical models estimate an increase of 185 and 57% of vertebral compressive force in the lumbar and thoracic spine respectively during changes of position from standing to 30° flexion [33]. A recent consensus defined "risky" activities as those that involve rapid, repetitive, weighted, end-range or sustained forward flexion, or twisting of the spine; these movements should be modified when possible, particularly in individuals at high risk of fracture. Further, lifting from or lowering objects to the floor, should be avoided in those at high risk [13•]. That said, telling a patient what *not* to do is a disincentive to physical activity participation, and may create fear. Rather, one can prescribe spine sparing practices; teach a patient a hip hinge for bending activities, and how to "step-to-turn," or turn the whole body, rather than twisting the spine. Individuals at low or moderate risk of fracture can likely participate in most activities they would like to do if they can practice spine sparing and modify the abovementioned "risky" activities. Furthermore, spine load is lower in the supine position than standing, and higher than both in seated [34], so prolonged sitting should be avoided, particularly in those with pain due to vertebral fractures. Unsupported upper extremity resistance training with weights while sitting should be avoided since slumping forward puts high loads on the spine [35].

Table 4. Aerobic physical activity recommendations for people with osteoporosis

Frequency	Intensity	Time (duration)	Type
Most days of the week	Moderate to vigorous intensity, moderate only for high risk. Moderate and vigorous correspond to 5–6 and 7–8 on a scale of 0 to 10 respectively [11]	≥ 150 min per week, in bouts of 10 min or more	Patient's preference, examples include walking, dancing, or cycling. Can also include leisure activities or household chores if sufficient intensity, e.g., heavy gardening and raking

Spine sparing key points:

Not all bending and twisting is bad. The most risky activities are those that involve rapid, repetitive, weighted, end-range, or sustained forward flexion or twisting of the spine.

Instead of telling patients what not to do (disincentive to physical activity), learn how to teach them a hip hinge movement, so that they can use it as a strategy for forward bending.

Patients at high risk of fractures may need to get help with all but light household activities, particularly in the presence of vertebral fractures or gait and balance difficulties.

Balance loads on both sides of body, e.g., groceries, rather than carrying on one side only.

Case studies

Case A: Male, 84 years of age, two osteoporotic vertebral fractures, and presents with history of two falls in the last month.

Because of history of falls, priority is incorporating balance and strength exercises.

- Balance exercises daily—start with static exercise progression that reduces base of support, e.g., stand with feet together, reduce use of upper limb support → stand in semi-tandem → stand in tandem → stand on one foot. Progressions can also include looking side to side while doing it, or adding a dynamic component, like tandem walking.
- Resistance exercises two or three times weekly, targeting major muscle groups, e.g., ten sit-stands, progressing to unassisted or half squats, ten wall push-ups, progressing to counter push-ups, ten step-ups on each leg, one leg at a time.

Case B: Female, 62 years of age, moderate risk of fracture, and walks daily for 30 min.

Because she is already getting aerobic physical activity, it is advisable that she add resistance training twice weekly at an intensity of 8–12 repetitions maximum (e.g., can do 8–12 repetitions with good form, but cannot do more than 12). To accomplish two goals at once, for the lower extremity, recommend resistance training exercises that also challenge balance because they require movement of the center of mass, like lunges or step-ups. Exercises that target muscles that stabilize the spine, like planks, side planks, and bird-dog, are also recommended. She may benefit from a consultation with an exercise professional.

A free one-page guide, booklet, and videos are available here: https://osteoporosis.ca/health-care-professionals/clinical-practice-guidelines/exercise-recommendations/.

Nutritional considerations

Initiating exercise when nutrition is inadequate may cause weight loss, or limit exercise capacity or muscle strength gains. Minerals, such as calcium, phosphorous, and magnesium; vitamins, such as vitamin D, A, and K; and

protein are important for bone health [36]. Adequate calcium and vitamin D, either through food or supplements, is encouraged to maximize effects of exercise on bone health [37]. Current guidelines for middle-aged and older adults suggest that adults 19 to 50 years should consume 1000 mg of calcium daily with 400 to 1000 IU of vitamin D, while people older than 50 years, 1200 mg of calcium daily with 800 to 2000 IU of vitamin D [38]. Recommended calcium doses consider both food and supplemental sources, but, ideally, the majority comes from food. Proteins optimize levels of IGF-I, which stimulates bone growth and increases calcium and phosphorus absorption in the gut and so has an important role in maintaining bone health [39]. Data from the Framingham Osteoporosis Study suggested that lower protein intake resulted in more bone loss at the spine and femur, when compared to higher protein consumption [40]. There are variations in protein intake and increased level of protein above 0.8 g/kg of body weight/day is associated with increased BMD [41]. With age, the anabolic response to protein may decline, and the PROT-AGE Group recommends 1.0–1.2-g protein/kg body weight per day for older adults, and more for active individuals [42]—a value higher than the recommended daily allowance (RDA). Some older adults do not even meet the RDA. Malnutrition and low protein intake have been associated with poor physical function [43]. Therefore, alongside a recommendation to participate in exercise should be a discussion about adequate protein and calorie intake. For further information, please refer to: https://osteoporosis.ca/bone-health-osteoporosis/nutrition/.

Future directions

There is a need to study the comparative efficacy of exercise interventions to determine optimal prescription. For example, studies comparing moderate to high intensity resistance training in individuals with low bone mass would be valuable, as would studies comparing trials with high impact to resistance training, or examining the value of power training in preventing bone loss or maintaining physical function. Studies looking at the effects of exercise on hard outcomes, such as fractures or hospitalizations, may be useful in convincing funders to subsidize exercise programming. Ultimately, an important barrier is implementation. Studies examining effective, pragmatic strategies to encourage adoption of physical activity guidelines and to sustain behavior long-term will aid in translating research to practice.

Conclusions

Adults with osteoporosis should participate in strength and balance training, along with moderate to vigorous aerobic physical activity. Activity restrictions should be avoided where possible, and instead, spine sparing strategies and fall prevention strategies that support safe participation in physical activity should be encouraged. Clinicians should ensure patients are consuming adequate calcium, vitamin D, and protein. While it may not be realistic to prescribe the recommended frequency, intensity, time,

and type for each exercise domain all at once, an astute clinician can explore a patient's goals and impairments, and work with the patient to come up with a realistic plan to get started.

Compliance with Ethics Guidelines

Conflict of Interest
Matteo Ponzano declares that he has no conflicts of interest.
Isabel B. Rodrigues declares that she has no conflicts of interest.
Lora M. Giangregorio declares that she has no conflicts of interest.

Human and Animal Rights and Informed Consent
This article does not contain any studies with human or animal subjects performed by any of the authors.

References and Recommended Reading

Recently published papers of particular interest have been highlighted as:
• Of importance
•• Of major importance

1.• Giangregorio L, El-Kotob R. Exercise, muscle, and the applied load-bone strength balance. Osteoporos Int. 2017;28:21–33.

A narrative review that pulls together research on the effects of exercise on falls, bone mineral density, muscle strength and size, and the muscle-bone relationship.

2. Kanis JA, McCloskey EV. Risk factors in osteoporosis. Maturitas. 1998;30:229–33.
3. Haentjens P, Magaziner J, Colon-Emeric CS, Vanderschueren D, Milisen K, Velkeniers B, et al. Meta-analysis: excess mortality after hip fracture among older women and men. Ann Intern Med. 2010;152:380–90.
4. Ioannidis G, Papaioannou A, Hopman WM, Akhtar-Danesh N, Anastassiades T, Pickard L, et al. Relation between fractures and mortality: results from the Canadian multicentre osteoporosis study. CMAJ. 2009;181(5):265–71.
5. Osteoporosis Canada. Osteoporosis facts and Statistics. Available from: https://osteoporosis.ca/about-the-disease/fast-facts/.
6. Cosman F, De Beur SJ, LeBoff MS, Lewiecki EM, Tanner B, Randall S, et al. Clinician's guide to prevention and treatment of osteoporosis. Osteoporos Int. 2014;25(10):2359–81.
7. Kerr, C., Bottomley, c., Shingler, S., Giangregorio, L., de Freitas, H.M., Patel, C., Randall, S., Gold, D.T. (2017) The importance of physical function to people with osteoporosis. Osteoporos Int.
8.•• Howe, T.E., Shea, B., Dawson, L.J., Downie, F., Murray, A., Ross, C., Harbour, R.T., Caldwell, L.M., Creed, G. (2011) Exercise for preventing and treating osteoporosis in postmenopausal women. Cochrane Database Syst Rev (7):CD000333.

A Cochrane meta-analysis that highlights the effect of exercise in general on bone mineral density in postmenopausal women, and subgroup analysis by exercise type.

9.• Sherrington C, Michaleff ZA, Fairhall N, Paul SS, Tiedemann A, Whitney J, et al. Exercise to prevent falls in older adults: an updated systematic review and meta-analysis. Br J Sports Med. 2017;51:1749–57.

A meta-analysis on the effects of exercise on falls in older people, including meta-regression to define what types of exercise are most effective, and recommendations.

10. Carspersen CJ, Powell KE, Cheistenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep. 1985;100(2):126–31.
11. Keteyian SJ. Graded exercise testing and exercise prescription. In: Erman JK, Gordon PM, Visich PS, Keteyian SJ, editors. Clinical exercise physiology. 3rd ed. USA: Human Kinetics; (2013). p. 61–88.
12.•• Giangregorio LM, Papaioannou A, Ashe MC, Heinonen A, Shipp K, Wark J, et al. Too fit to fracture: exercise recommendations for individuals with osteoporosis or osteoporotic vertebral fracture. Osteoporos Int. 2014;25(3):821–35.

The first international consensus to define physical activity recommendations for people with osteoporosis, considering outcomes important to patients and providers, e.g., falls, fractures, bone mineral density, quality of life, and mobility.

13.• Giangregorio LM, McGill S, Wark JD, Laprade J, Heinonen A, Ashe MC, et al. Too fit to fracture: outcomes of a Delphi consensus process on physical activity and exercise recommendations for adults with osteoporosis with or without vertebral fractures. Osteoporos Int. 2015;26(3):891–910.
An international Delphi consensus on physical activity recommendations and answers to commonly asked questions by patients.
14. Manual for the fall prevention classification system (2017) ProFaNe Taxonomy.
15. El-Khoury F, Cassou B, Charles MA, Dargent-Molina P. The effect of fall prevention exercise programmes on fall induced injuries in community dwelling older adults: systematic review and meta-analysis of randomised controlled trials. BMJ. 2013;347:f6234. https://doi.org/10.1136/bmj.f6234.
16. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, Salem GJ, et al. ACSM position stand. Exercise and physical activity for older adults. Med Sci Sports Exerc. 2009;41(7):1510–30.
17. Karinkanta S, Piirtola M, Sievanen H, Uusi-Rasi K, Kannus P. Physical therapy approaches to reduce falls and fracture risk in older adults. Nat Rev Endocrinol. 2010;6(7):396–407.
18. Tricco AC, Thomas SM, Veroniki AA, Hamid JS, Cogo E, et al. Comparisons of interventions for preventing falls in older adults a systematic review and meta-analysis. JAMA. 2017;318(17):1687–99.
19. Peterson MD, Sen A, Gordon PM. Influence of resistance exercise on lean body mass in aging adults: a meta-analysis. Med Sci Sports Exerc. 2011;43(2):249–58.
20. Borde R, Hortobágyi T, Granacher U. Dose–response relationships of resistance training in healthy old adults: a systematic review and meta-analysis. Sports Med. 2015;45(12):1693–720.
21. Liu CJ, Latham NK. Progressive resistance strength training for improving physical function in older adults. Cochrane Database Syst Rev. 2009;8(3):CD002759.
22. Pahor M, Guralnik JM, Ambrosius WT, Blair S, Bonds DE, Church TS, et al. Effect of structured physical activity on prevention of major mobility disability in older adults. JAMA. 2014;311(23):2387–96.
23. Martyn-St James M, Carrol S. High-intensity resistance training and postmenopausal bone loss: a meta-analysis. Osteoporos Int. 2006;17:1225–40.
24. Zhao R, Zhao M, Xu Z. The effects of differing resistance training modes on the preservation of bone mineral density in potmenopausal women: a meta-analysis. Osteoporos Int. 2015;26:1605–18.
25. Kelley GA, Kelley KS, Kohrt WM. Exercise and bone mineral density in men: a meta-analysis of randomized controlled trials. Bone. 2013;53(1):103–11.
26. Robling AG. Is bone's response to mechanical signals dominated by muscle forces? Med Sci Sport Exerc. 2009;41(11):2044–9.
27. Watson SL, Weeks BK, Weis LJ, Harding AT, Horan SA, Beck BR. High-intensity resistance and impact training improves bone mineral density and physical function in postmenopausal women with osteopenia and osteoporosis: the LIFTMOR randomized controlled trial. J Bone Miner Res. 2018;33:211–20.
28. Canadian Society for Exercise Physiology Physical Activity Guidelines (2017) http://www.csep.ca/CMFiles/Guidelines/CSEP_PAGuidelines_adults_en.pdf; accessed on Dec 16, 2017.
29. American College of Sports Medicine Physical Activity Guidelines (2017) http://www.acsm.org/public-information/acsm-journals/guidelines; accessed on Dec 16, 2017.
30. Centers for Disease Control and Prevention Physical activity guidelines for Adults (2017) https://www.cdc.gov/cancer/dcpc/prevention/policies_practices/physical_activity/guidelines.htm; accessed on Dec 16, 2017.
31. Nichols DL, Pavlovic A. Osteoporosis. In: Erman JK, Gordon PM, Visich PS, Keteyian SJ, editors. Clinical exercise physiology. 3rd ed. USA: Human Kinetics; (2013). p. 447–459.
32. Skidmore CJ, Saccone M, Mittmann N, Giangregorio L. Physical activity pattern and preference in women with low bone mass. J Bone Miner Res. 2011;26(Suppl 1)
33. Iyer S, Christiansen A, Roberts BJ, Valentine MJ, Manohram RK, Bouxsein ML. A biomechanical model for estimating loads on thoracic and lumbar vertebrae. Clin Biomech. 2010;25:853–8.
34. Myers ER, Wilson SE. Biomechanics of osteoporosis and vertebral fracture. Spine (Phila Pa 1976). 1997;22(24 Suppl):25S–31S.
35. Bonner FJ, Sinaki M, Grabois M, Shipp KM, Lane JM, Lindsay R, et al. Health professional's guide to rehabilitation of the patient with osteoporosis. Osteoporos Int. 2003;14(Suppl 2):S1–S22.
36. Ellert G, Low A, Wade J. The osteoporosis book. 4th ed. Trelle Enterprises; 2016. 288 p.
37. Rizzoli R, Bischoff-Ferrari H, Dawson-Hughes B, Weaver C. Nutrition and bone health in women after the menopause. Womens Health (Lond). 2014;10(6):599–608.
38. Osteoporosis Canada (2017) Bone health and osteoporosis: nutrition.
39. Locatelli V, Bianchi VE (2014) Effect of GH/IGF-1 on bone metabolism and osteoporsosis. Int J Endocrinol.
40. Hannan MT, Tucker KL, Dawson-Hughes B, Cupples LA, Felson DT, Kiel DP. Effect of dietary protein on bone loss in elderly men and women: the Framingham osteoporosis study. J Bone Miner Res. 2000;15(12):2504–12.
41. Darling AL, Millward DJ, Torgerson DJ, Hewitt CE, Lanham New SA. Dietary protein and bone health: a systematic review and meta-analysis. Am J Clin Nutr. 2009;90:1674–92.
42. Bauer J, Biolo G, Cederholm T, Cesari M, Cruz-Jentoft AJ, Morley JE, et al. Evidence-based recommendations for optimal dietary protein intake in older people: a position paper from the PROT-AGE study group. J Am Med Dir Assoc. 2013;14(8):542–59.

43. Gregorio L, Brindisi J, Kleppinger A, Sullivan R, Mangano KM, Bihuniak JD, et al. Adequate dietary protein is associated with better physical performance among post-menopausal women 60-90 years. J Nutr Health Aging. 2014;18(2):155–60.