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Review

Exercise and Sports Science Australia (ESSA) position statement on exercise prescription for the prevention and management of osteoporosis

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ABSTRACT

Objectives: Osteoporotic fractures are associated with substantial morbidity and mortality. Although exercise has long been recommended for the prevention and management of osteoporosis, existing guidelines are often non-specific and do not account for individual differences in bone health, fracture risk and functional capacity. The aim of the current position statement is to provide health practitioners with specific, evidence-based guidelines for safe and effective exercise prescription for the prevention or management of osteoporosis, accommodating a range of potential comorbidities.
Design: Position statement.
Methods: Interpretation and application of research reports describing the effects of exercise interventions for the prevention and management of low bone mass, osteoporosis and osteoporotic fracture.
Results: Evidence from animal and human trials indicates that bone responds positively to impact activities and high intensity progressive resistance training. Furthermore, the optimisation of muscle strength, balance and mobility minimises the risk of falls (and thereby fracture), which is particularly relevant for individuals with limited functional capacity and/or a very high risk of osteoporotic fracture. It is important that all exercise programs be accompanied by sufficient calcium and vitamin D, and address issues of comorbidity and safety. For example, loaded spine flexion is not recommended, and impact activities may require modification in the presence of osteoarthritis or frailty.
Conclusions: Specific guidelines for safe and effective exercise for bone health are presented. Individual exercise prescription must take into account existing bone health status, co-morbidities, and functional or clinical risk factors for falls and fracture.

1. Background

What is osteoporosis? The widely accepted definition of osteoporosis, developed by a US National Institutes of Health Consensus Panel in 2000, is “a skeletal disorder characterised by compromised bone strength predisposing a person to an increased risk of fracture”.[1] The operational definition of osteoporosis of the World Health Organization (WHO),[2] and one that continues to be widely applied due to its diagnostic utility, is based on an estimation of bone mineral density (BMD, g/cm^2) measured by dual-energy x-ray absorptiometry (DXA).[2] According to the WHO, a DXA-derived BMD T-score (standard deviation, SD) of 2.5 or more below the mean for young adult Caucasian women constitutes a diagnosis of osteoporosis. A BMD T-score that falls between -1.0 and -2.5 SD is classified as osteopenia (low bone mass). In practice, race and sex-specific T-scores are typically used. While a diagnosis of osteoporosis is associated with a 2- to 3-fold increased risk of sustaining a fragility fracture,[3] it is estimated that more than 50% of women and 70% of men who sustain a low trauma fragility fracture actually have a diagnosis of osteopenia rather than osteoporosis.[4] Those data suggest that other skeletal factors beyond BMD, such as the size (cross-sectional area), structure (macro- and micro-architecture) and intrinsic properties (porosity, matrix mineralisation, collagen traits) of bone also play an important role

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in determining bone strength and fracture risk, along with non-skeletal factors such as muscle strength and balance.[5] Best research practice therefore includes the characterisation of bone strength using three-dimensional imaging techniques such as peripheral quantitative computed tomography (pQCT) or magnetic resonance imaging (MRI), in addition to BMD. Osteoporotic fracture can occur at virtually any skeletal site; however, the bones most frequently affected are the spine, hip, wrist, humerus and pelvis. Hip fractures are the most devastating in terms of morbidity and mortality. As more than 95% of hip fractures occur as a consequence of a fall, strategies to optimise bone strength and reduce fall risk are likely to prevent fractures most effectively.

What is the cost? Osteoporosis imposes a major personal, societal and economic burden owing to the morbidity and mortality associated with fractures. Currently, nearly two-thirds of Australians over 50 suffer from low bone mass (30% of whom are male).[6] In 2013, there were almost 400 osteoporotic fractures per day in Australia; a figure that is projected to increase to 500 per day by 2022.[6] The cost of osteoporosis and osteopenia to Australians in 2012, including direct and indirect costs, was estimated to be $2.75 billion, and is projected to rise to $3.84 billion in 2022, with a 10-year expected cumulative cost of $33.6 billion.[6]

As bone is a dynamic tissue with the capacity to adapt to changing load requirements, exercise is widely recognised as a vital physical stimulus for the development and maintenance of optimal bone strength throughout life. While the precise dose of exercise to promote positive skeletal adaptations throughout life remains to be determined, current evidence indicates that the effects of exercise on bone are modality-, dose- and intensity-dependent. The goal of the current position statement is to provide specific exercise recommendations for the prevention and/or management of osteoporosis and fragility/low trauma fractures, within the limits of existing evidence.

2. Role of exercise in the prevention and treatment of low bone mass

Regular physical activity provides a multitude of health benefits, but not all exercise modalities are equally osteogenic. The dogma that prolonged aerobic training, such as swimming, cycling, and walking, is ubiquitously beneficial to *all* body systems is inconsistent with empirical evidence suggesting none of those activities provide a notable stimulus to bone.[7–9] Evidence from cohort studies that higher levels of self-reported physical activity are related to higher bone mass is often inappropriately interpreted as evidence that *any* activity will improve bone. While there are some reports that brisk walking[10] or walking combined with other impact loading activities may help postmenopausal women offset age-related bone loss,[11] a meta-analysis of intervention studies reveals minimal or no effect of regular walking and other low intensity activities on bone in peri- and postmenopausal women.[12] There is also evidence that the inclusion of walking in an exercise program can expose previously sedentary or frail older adults to an increased risk of falling, thereby increasing the risk of fracture.[13] Thus, despite the benefits of regular walking on aerobic fitness, adiposity, and other cardio-metabolic factors, simply prescribing walking in isolation is insufficient to optimise bone health, and has little or no effect on other fall- and fracture-related risk factors such as muscle mass, strength and balance in postmenopausal women.[7]

By contrast, other forms of exercise *do* have the capacity to improve bone health. Many animal studies have informed our current understanding of the adaptive responses that can be expected from bone according to magnitude, rate and frequency of loading. This evidence indicates that loading must (1) be dynamic not static (i.e., cyclic not continuous),[14] (2) induce relatively high bone strains (deformations),[15] and (3) be applied rapidly.[16] Relatively few loading cycles (repetitions) are required to elicit an adaptive skeletal response if adequate load intensity is achieved.[17] In fact, short bouts separated by periods of rest are more effective than the same number of loads performed all at once, as bone cells will desensitise to repetitive loading.[18] Finally, as bone will adapt to customary patterns of loading (e.g. running), diversification of loading (e.g. multidirectional movements) is required to stimulate an adaptive skeletal response.[19]

Cross-sectional studies consistently demonstrate that athletes engaged in high- or unusual-impact weight-bearing sports with rapid rates of loading such as gymnastics,[20] volleyball,[21] basketball,[22] ballet dancing,[23] football,[24] power lifting,[25] tennis/squash,[26] and figure skating,[27] have superior bone mass at loaded skeletal sites compared to non-athletes or athletes in non-weight-bearing or lower-impact sports.

Naturally, it is not practical to create exercise guidelines for osteoporosis prevention or management based on technically and physically challenging sports. More feasible activities to optimise bone health at different stages of life have been examined in randomised controlled trials (RCTs) designed to employ the principles of optimal loading from animal studies. As a comprehensive summary of all studies is beyond the scope of this paper, only results from the most methodologically sound RCTs form the basis of our recommendations.

Overall, RCTs and meta-analyses indicate that exercise training involving certain forms of weight-bearing impact exercise, such as hopping and jumping, and/or progressive resistance training (PRT), alone or in combination (multi-modal programs), can improve the bone health of children and adolescents,[28] pre-[29] and postmenopausal women,[30] and older men.[31] Effect sizes are smaller than those observed in animal or cross-sectional studies of athletes, as genetic and environmental variations influence the response. Many trials have reported relatively modest benefits of exercise to BMD in adulthood - preventing loss or promoting gains in the order of only 1–3% following exercise interventions of between 24 and 104 weeks.[32] It is possible the exercise protocols of those studies applied an insufficient stimulus to increase BMD. Exercise training may, however, enhance whole bone strength, independent of changes in BMD, through alterations in bone structure and/or localized adaptation in bone distribution at sites subjected to the greatest strain.[33,34] An increase in cortical thickness due to load-induced periosteal apposition and, to a lesser extent reduced endocortical resorption, will increase the resistance of a bone to bending.[35] However, findings from the limited number of trials that have examined the effects of exercise on bone structure and strength are mixed.[36]

The greatest skeletal benefits to the spine and hip from PRT have been achieved when the resistance (weight) was progressively increased over time, the magnitude of loading was high[37] (around 80–85% 1 repetition maximum [RM]), training was performed at least twice a week, and large muscles crossing the hip and spine were targeted.[30] The spine may respond to PRT more than the hip.[38] Power training (high-velocity concentric PRT) may be indirectly beneficial to bone owing to a slightly greater effect on muscle power and functional performance than regular strength training.[39]

Programs that incorporate moderate-to-high weight bearing impact loads (>2 times body weight) that are progressive, novel and multidirectional can be osteogenic for premenopausal women and older adults.[40,41] Relatively few impacts (10–50/day, 3 times/week)[42] are required to stimulate the response in premenopausal women, but added benefit may be derived from more frequent exposure (4–7 days/week).[43] Impact loading appears to generate a greater response at the hip than the spine in premenopausal women.[44] In older women, the skeletal response to high impact activities is less consistent, with some but not all trials reporting positive effects.[45,46] It is possible that technique and compliance (which may be related to pain from comorbidities such as osteoarthritis) has governed the modest response to weight-bearing impact exercise observed in older individuals. Novel or diverse loading patterns may be particularly important for effective stimulation of bone in older adults not able to tolerate high magnitude impact loads,[47] but the safety and efficacy of such movement patterns for bone and joints in the older person requires further investigation. Some exercise programs that have combined both high intensity PRT and moderate-to-high impact activities such as running, jumping, skipping and high impact aerobics have improved multiple musculoskeletal outcomes for both older women and men, including BMD, and muscle mass, strength and function.[48,49] The ground reaction forces associated with many common impact activities have been described,[50] in order to inform efficacious exercise prescription for bone.

In light of the strong association between falls and osteoporotic fractures, any exercise program designed to prevent fractures in the elderly, particularly those with known risk factors for falling, should include activities to optimise muscle function, balance and gait stability. In most cases, falls prevention programs that are focused on balance and mobility, including Tai Chi or the well-known Otago Home Exercise Program, do not induce the necessary bone strain to stimulate adaptive skeletal benefits in older people,[51,52] but may play a vital role in neuromuscular conditioning.[53] Many older adults fall when their attention is divided by dual tasking (e.g. walking whilst maintaining a conversation).[54] Dual task training, such as exercising whilst performing a secondary cognitive and/or motor task, may improve functional performance under both single and dual task conditions.[55]

Certain other types of exercise that do not notably enhance bone mass or directly reduce fall risk may be beneficial. For example, back extension exercises strengthen the muscles[56] that oppose kyphotic curvature in the thoracic spine that frequently develops following disk degeneration and vertebral wedge fracture. As kyphotic posture is associated with impaired balance in the elderly with osteoporosis,[57] back extension exercise may indirectly reduce falls risk. There is some evidence that back extension exercise training reduces vertebral fractures in postmenopausal women in the long term, even in the absence of increased bone mass.[56]

No exercise recommendations for the prevention of osteoporosis would be complete without reference to the powerful influence of age on the adaptive response of bone to loading. It has been theorised that achieving a 10% higher peak bone mass in young adulthood could delay the development of osteoporosis by around 13 years, and ultimately reduce the lifetime risk of fracture by 50%.[58] While there is no experimental evidence from large life-long studies required to test such a notion, a growing body of evidence suggests that adaptations to mechanical loading in youth translate to greater bone strength over a lifetime.[35] Further, it is generally accepted that the skeleton is more responsive to exercise in childhood than in adulthood and older age.[26] Additionally, the benefits of targeted exercise appear to be sustained, even after the intervention ceases, if initiated in childhood,[59] but not in adulthood.[60] Age-related bone loss is very evident in adults who are inactive.[61,62] For this reason, although osteoporosis is considered to be primarily a condition of old age, exercise prescription for the prevention of osteoporosis should begin in childhood and continue throughout life. Recent longitudinal data however indicates that it's never too late to start, as exercise training may prevent fracture even when initiated post menopause.[63] Exercises that are appropriate to build bone in childhood mirror those that are most effective in adulthood (high impact weight-bearing activities that engage large muscle groups), however, frailty and comorbidity may temper exercise capacity for some older adults.

3. Exercise prescription – boundaries of the evidence

The application of osteogenic exercise principles from the results of animal studies to the human condition has not been a trivial matter. Human data are confounded by an inability to control many variables that exert profound influence on bone; including genes, certain diseases, medications, diet and exercise history. To the best of our knowledge, none of the many human trials have managed to fully control those constraints. As a result, precise recommendations for the optimal modality, dose, frequency and intensity of exercise required to strengthen bones for all individuals and under all circumstances are yet to be fully validated. There is, however, strong evidence to support the basic principles outlined below.

Exercise intensity is key to effective exercise prescription for bone; however the definition of intensity for PRT and impact loading is not straightforward. We employ a combination of an established classification system for PRT,[64] ground reaction force data,[50] and the Borg scale of perceived exertion[65] to clarify our classifications of intensity in our exercise prescription guidelines (Table 1 legend).

Falls prevention trials have rarely targeted balance alone as an outcome measure, and the intensity of challenge to balance has been poorly described,[66] thus specific guidelines for effective balance training to prevent osteoporotic fracture are lacking. The recommendations for balance training in Table 1 therefore represent an extrapolation of dose from the findings of a recent meta-analysis of exercise interventions to prevent falls.[13]

4. Exercise prescription – recommendations (summarised in Table 1)

An exercise program of moderate to high-impact weight-bearing activities, high intensity PRT and balance training forms the basis of the current recommendations. While frail individuals would theoretically benefit from a similar program of osteogenic exercise, limitations in clinical or functional capacity may necessitate a more conservative approach, with a particular focus on optimising muscle function and enhancing balance to reduce the risk of falling.[13,53]

Thus, an exercise prescription should take account of an individual's BMD and functional and clinical risk factors for falls and fracture. The latter could include: age, frailty, sarcopenia, loss of height, family history of osteoporosis, presence of back pain or osteoarthritis, history of fractures and falls, presence of certain diseases known to affect bone metabolism, early or surgically-induced menopause, low testosterone (men), prolonged use of certain drugs (e.g. corticosteroids), inadequate dietary calcium, vitamin D deficiency, excessive alcohol intake, smoking, and previous physical activity. As falls are a major cause of fracture, gait, balance, mobility, transfer ability, range of motion, muscle strength (particularly of the trunk, elbow, hip and knee extensors) and vision should also be considered. Individual goals, preferences and interests should be considered in order to maximise exercise adherence and long-term compliance.

The following section outlines the exercise goals and prescription guidelines for individuals classified into three levels of risk of low trauma fracture (see also Table 1).

1. *Low-risk individuals*: We define "low risk" of low trauma fracture as being asymptomatic of osteoporosis, with 'normal' BMD (T-score above -1.0 SD) and functional status, and no clinical risk factors for falls or fracture (e.g. children/adolescents and healthy adults). The goal of a bone-targeted exercise program for low-risk individuals is to *maximise* bone mass and strength, and to

Table 1
Exercise prescription for the prevention and management of osteoporosis according to level of risk for fragility fracture.

Exercise mode	Exercise components	Low-risk* individuals (prevention of OP)	Moderate-risk** individuals (prevention of OP)	High-risk*** individuals (management of OP and prevention of falls)
Impact loading	Vertical and multidirectional jumping, bounding, hopping, skipping rope, drop jumps and bench stepping. Progress BW intensity by increasing heights for activities such as bounding and drop jumping, adding weighted vests and changing directions. Impact loading can be interspersed between balance and resistance training exercises. using weighted vests, changing direct of movement	Intensity: High impact activities† (>4 BW), as tolerable Frequency: 4–7 d/wk Sets/Repetitions: 50 jumps per session (3–5 sets of 10–20 repetitions with 1–2 min rest between sets)	Intensity: Moderate-to-high impact activities‡ (>2 BW), as tolerable Frequency: 4–7 d/wk Sets/Repetitions: 50 jumps per session (3–5 sets of 10–20 repetitions with 1–2 min rest between sets)	Intensity: Moderate impact activities □ (2–3 BW), within the limits of pain, increasing as tolerated. Frail individuals will require a period of PRT to develop adequate strength to perform some impact activities. Frequency: 4–7 d/wk Sets/Repetitions: Aim to work up to 50 repetitions over time (5 sets of 10 repetitions with 1–2 min rest between sets) Frail individuals should be supervised and exercise within reach of a railing or other stable support.
Progressive resistance training (PRT)	8 exercises per session targeting major muscle groups attached to the hip and spine including (on a rotating system): weighted lunges, hip abduction/adduction, knee extension/flexion, plantar-/dorsi-flexion, back extension, reverse chest flys, and abdominal exercises, or a smaller number of compound movements such as squats and deadlifts.	Intensity: High to very high (80–85% 1RM; ≥16 on Borg 6–20 point RPE scale or 'Very hard')¥ Frequency: 2 d/wk Sets/Repetitions: 2–3 sets of 8 repetitions Consider including high velocity (rapid) PRT exercises to enhance muscle power and function Avoid deep forward spine flexion. Training in technique and supervision is essential.	Intensity: High to very high (80–85% 1RM; ≥16 on Borg 6–20 point RPE scale or 'Very hard')¥ Frequency: 2 d/wk Sets/Repetitions: 2–3 sets of 8 repetitions Consider including high velocity (rapid) PRT exercises to enhance muscle power and function Avoid deep forward spine flexion. Training in technique and supervision is essential.	Intensity: High to very high (80–85% 1RM; ≥16 on Borg 6–20 point RPE scale or 'Very hard')¥ Frequency: 2 d/wk Sets/Repetitions: 2–3 sets of 8 repetitions Consider including high velocity (rapid) PRT exercises to enhance muscle power and function Avoid deep forward spine flexion. Training in technique and supervision is essential.
Balance training	Standing and moving exercises with gradual reduction in base of support to standing on one foot, perturbing the centre of mass with leaning and reaching then regaining balance with minimal use of support from the upper extremities. e.g. Tai Chi, single leg stance, tandem stance, tandem walk, backwards, sideways and crossover walks, circle and pivot turns, figure of eight walks, stepping over and avoiding obstacles, walking on uneven surface. Progress by altering surface (foam mats) and reducing base of support, longer or faster steps, heel and toe walks, raised arms walk, withdrawing vision during balance tasks, and dual tasking (e.g. cognitive task such as counting backwards or naming animals, combined with balance activities).	Intensity: Challenging Frequency: Incorporate balance activities where possible into strength and impact elements of the exercise programme. Tasks performed with eyes closed should be done in proximity to a railing or other secure support.	Intensity: Challenging Frequency: 4 sessions/wk Sets/Repetitions: 30 min of a variety of balance exercises per session; at least 10 sec per balance exercise and at least 10 steps forward and back for mobility exercises, increasing as tolerated to longer durations Could be accomplished within other exercise bouts during the course of a week Tasks performed with eyes closed should be done in proximity to a railing or other secure support.	Intensity: Challenging Frequency: 4 sessions/wk Sets/Repetitions: 30 min of a variety of balance exercises per session; at least 10 sec per balance exercise and at least 10 steps forward and back for mobility exercises, increasing as tolerated to longer durations Could be accomplished within other exercise bouts during the course of a week Frail individuals should be supervised to prevent falls during balance training and exercise within reach of a railing or other secure support.

* Low-risk = asymptomatic individual with normal BMD (T-score above -1.0 SD) and functional status, and no clinical risk factors for falls or fracture
** Moderate-risk = low bone mass (T-score -1.0 to -2.5 SD) and/or certain clinical or functional risk factors for fracture
*** High-risk = very low bone mass (T-score less than -2.5 SD/osteoporosis) and/or a number of clinical or functional risk factors for fracture
† high impact activities (>4 BW) include landings from exertional jumps such as high vertical jumps, star jumps, tuck jumps, and drop landings; including within sports such as volleyball, basketball, gymnastics, ballet, Australian Rules Football, etc. □ moderate impact activities (2–3 BW) include running, stride jumps, jump rope, side steps, highland-type dancing, jump take offs and hops; including within sports such as, racquet sports, track events, most field sports and martial arts that include frequent jumps.
‡ moderate-to-high impact activities (> 2 BW) include all of the activities listed for the moderate and high impact categories (Adapted from Weeks and Beck[50])
¥ Rate of progression of PRT for novice exercisers should be 50%, 60%, 70%, and 80% of 1RM for the first 4 sessions to ensure correct technique and appropriate muscle conditioning. Intensity and rate of progression will vary based on level of individual risk within each category.
#Challenging = attempting a level not yet mastered (i.e. the entire time, distance or activity cannot be completed without losing balance).
BW, body weight; OP, osteoporosis; RM, repetition maximum, the maximum weight that can be lifted once; RPE, rating of perceived exertion (Borg 6–20-point scale categories of RPE intensity[65]).

improve muscle strength and functional capacity. Thus, a variety of progressively increasing impact activities that include jumps and/or hops and multidirectional weight-bearing exercises, as well as recreational sporting activities (e.g. gymnastics, basketball, netball, volleyball), and PRT (including major muscle groups and back extension) are recommended. Balance training should be initiated to prevent age-related deterioration. Low intensity repetitive aerobic activities (e.g. walking) or non-weight bearing activities (swimming, cycling) are not recommended, being largely ineffective for improving BMD, but could form part of a comprehensive program to improve aerobic fitness and other health outcomes.

2. *Moderate-risk individuals*: We define "moderate risk" of low trauma fracture as having low bone mass (*T*-score −1.0 to −2.5 SD) and/or certain clinical or functional risk factors for fracture (described above). For moderate-risk individuals, the goal of an exercise program is to *preserve or improve* bone mass and strength, and improve muscle strength, power, and balance. Similar weight-bearing impact activities and PRT activities as prescribed for low-risk individuals are recommended. More moderate impact activities such as running, jump rope, racquet sports, and field sports may be more appropriate for individuals approaching a *T* score of −2.5. For some, a period of moderate advancing to high-intensity PRT may also be required to condition the musculoskeletal system before introducing impact exercises. There should be demonstrated pain-free competency in all activities. Progressively challenging balance, posture and mobility exercises should be a greater focus than for low-risk individuals, to prevent falls. Specific details about the type and progression of exercise for falls prevention have been described previously.[67]
3. *High-risk individuals*: We define "high risk" of low trauma fracture as having osteoporosis (*T*-score less than −2.5 SD), previous fracture, and/or multiple risk factors for fracture. The absolute magnitude of load that can be applied to an osteoporotic skeleton without incurring a fracture is unknown. Counter to the traditional notion that high-intensity loading places osteoporotic bone at acutely increased risk of fracture, emerging evidence in osteopenic and osteoporotic women over 60 years of age (mean age 66.1 years, mean *T*-score <−2.2 at the spine) indicates that high load PRT and moderate impact loading may not only improve bone mass and reduce kyphosis, but be safe and well-tolerated in this population.[68] However, supervision, an emphasis on correct technique, gradual loading increments, and avoidance of activities that might increase falls, are essential.

Recent consensus guidelines recommended that individuals with vertebral osteoporosis engage in a multicomponent exercise program that includes PRT, in combination with mobility and balance training, provided with guidance on safe movements.[69] High-risk individuals will benefit from improved muscle strength in the back, legs, upper arms and core, and enhanced posture, balance and co-ordination. Exercises for lower extremity muscles should focus on every major group around each joint. Back strengthening and postural exercises will reduce forward head posture, improve shoulder range of motion and trunk stability, and reduce vertebral fractures over time.[56] Elbow extensor strength is critical for facilitating transfers (moving the whole body using only the arms) and is related to reduced risk of nursing home admission after hip fracture.[70]

Exercises should be introduced in the order dictated by impairment, that is, to stand up and walk across a room, muscle strength, balance, and endurance will be required, in that order. Therefore, the exercise prescription progression for someone who is frail to the point of transfer and mobility impairment is most logically PRT, then balance training, followed by weight bearing activity.

Table 1 provides a baseline exercise prescription for the prevention or management of osteoporosis. A minimum of two weekly sessions of PRT, four to seven weekly sessions of impact activities, and balance training are recommended. Greater neuromusculoskeletal benefits could be expected with increased dose and/or intensity of loading, however an upper limit of efficacy is not known. A period of conditioning at lower intensity may be necessary to achieve the intensities described for impact and PRT (see Table 1 footnote).

5. Special considerations

Individuals with the lowest bone mass and/or the lowest levels of previous exercise exposure are likely to exhibit the greatest response to increased exercise loading.[71] Those with average or above average bone health are unlikely to experience notable increases in bone mass in response to exercise, unless the nature of the loading differs substantially from and/or imposes considerably higher levels of bone strain than habitual patterns. However, increasing muscle strength and balance will reduce fall risk and are therefore recommended for such individuals.

Table 2 provides specific modifications to exercise recommendations for persons with common comorbidities, including osteoarthritis, frailty/neuromuscular impairment, and/or cardiopulmonary disease.

The clinical community has traditionally discouraged repetitive impact exercise for individuals with hip or knee osteoarthritis (OA). However, a recent study has shown that progressive high impact exercise training can benefit bone without adversely affecting knee joint cartilage of mildly osteoarthritic postmenopausal women.[72] As it is not known whether more severe forms of arthritis would respond as favourably, it may be prudent to prescribe low-to-moderate impact activities and moderate-to-high intensity PRT in this population until further evidence is available.

The importance of dietary calcium and vitamin D to bone health is well-established. The skeletal benefits of exercise may be attenuated against a background of inadequate dietary calcium.[73] In addition, vitamin D deficiency has been associated with sarcopenia and an increased risk of falling and fracture in old age.[74] Whether vitamin D supplementation will prevent falls or fracture is controversial.[75] Nevertheless, to maximise the benefits of exercise for musculoskeletal health and function it is recommended to achieve the recommended dietary intakes of calcium from dietary sources and sufficient vitamin D from sun exposure or supplements.

6. Contraindications to exercise

As with any exercise recommendation, certain caveats apply. Individuals with known vertebral osteoporosis/kyphosis should avoid deep forward flexion activities, particularly when lifting a load or carrying an object (e.g. rowing, lifting weights with a flexed spine, yoga, Pilates, bowling, sit-ups, house and yard work), in order to avoid vertebral wedge fractures. Similarly, high-impact activities and exercises that require rapid and/or loaded twisting, and explosive or abrupt actions (e.g., golf, racquet sports) may be contraindicated for some individuals at high risk of low trauma fracture, particularly those with vertebral osteoporosis, poor balance, or osteoarthritis. High-risk individuals should receive training in safe lifting and postural techniques to avoid dangerous or excessive loading during common daily tasks or recreational activities. Exercise prescription for individuals with pain, kyphosis and/or poor balance must be individualised and supervised. Exercises that are difficult to perform on dry land or standing may be conducted in warm water, seated in a chair, or prone, but the latter are unlikely

Table 2
Recommended modifications to bone exercises for people with physical limitations.

Exercise modality	Modification for Arthritis	Modification for Frailty/Neuromuscular Impairment	Modification for Cardiovascular/Pulmonary Disease
Progressive resistance training [a]	Provide careful attention to form to prevent injuries May need to limit range to pain-free motion, provide good back support, adjust machines or free weights to accommodate joint deformities or restrictions Intensity may need to be individualized for some exercises Maintain a fixed dose of medication on a regular schedule if arthritis pain is chronic	Usually little modification required May need to alter certain exercises for neurological impairment Supervision usually needs to be more intensive for safety and progression	Usually no modification required If angina or ischemia is provoked by exercise, keep intensity below the level at which this occurs May need to perform exercises in seated rather than standing positions due to fatigue or poor balance Avoid breath holding/Valsalva manoeuvre, isometric contractions longer than 5–10 seconds, or tight handgrip during weightlifting
High impact exercise	May need to reduce or eliminate high ground-reaction forces (replace jumps with heel drops) Substitute power training (rapid concentric muscle contraction against moderate-to-high load on weight-lifting machine) to produce rapid onset of high muscle contraction forces like a take-off in a jump, but with no impact landing	Start with heel drops instead of jumps Perform exercises under supervision and holding onto a support rail initially Gradually reduce hand support as tolerated	Keep training intensity below the level that causes ischemia or severe dyspnoea
Balance training [b]	May not be able to place full body weight on osteoarthritic joints – use less painful leg to perform one-legged postures, assist weight bearing with use of cane Keep sessions short to avoid pain from prolonged weight bearing Reduce angle of flexion at knee during T'ai Chi movements	Perform exercises under supervision and holding onto a support rail initially Gradually reduce hand support as tolerated	Usually no modifications necessary

Adapted from Fiatarone Singh.[79]
[a] Recommended exercises include leg press, squats, knee extension, hip abduction, hip flexion, dorsiflexion, military press, lat pull down, back extension, abdominal training
[b] One-legged standing, tandem walking, crossover walking, turning, stepping over objects, leaning to limits of sway, etc.

to be osteogenic. A summary of potential risks and management strategies is provided in Table 3.

Finally, exercise recommendations for the prevention or management of osteoporosis must be undertaken within the boundaries of exercise restrictions for comorbid conditions.

7. Gaps in the literature

There are two main gaps in the literature. The first is that there has never been a study conducted with sufficient statistical power and duration to adequately examine dose responses to exercise at all stages of life and levels of risk of low trauma fracture. Consequently, it is not possible to provide definitive guidelines for the precise amount, intensity and duration of every exercise that will stimulate optimal gains in bone for every individual. The second is that although it is clear that appropriately prescribed exercise enhances bone health and reduces falls risk, there is a paucity of experimental evidence that exercise will prevent osteoporotic fractures. It has been estimated that to power the definitive exercise intervention trial for a hip fracture endpoint in women, a sample size of over 7000 individuals at high risk of low trauma fracture would be required, which would take many years to recruit at a prohibitive financial cost.[76] The number would be far greater for a sample of men.

There is, however, evidence to support fracture prevention efficacy of exercise from Cochrane reviews,[53,77] meta-analyses,[78] and a small but long-term targeted exercise intervention of postmenopausal women.[63] In general, the reviews and meta-analyses of the effects of physical activity and exercise on bone report a protective effect with a risk reduction of up to 50% or more. Meta-analyses and systematic reviews must be interpreted with caution in light of (1) replication of sampling bias from cohort studies,[76] (2) reporting of fractures as only a secondary endpoint or adverse event in most exercise interventions, and (3) evidence of publication bias.[78] A non-randomised exercise trial for early postmenopausal women observed significantly reduced risk of low trauma fracture in the exercise group after 16 years (RR 0.51, 95% CI 0.23–0.97; $p = 0.046$).[63] Nevertheless, insufficient direct experimental evidence limits the ability to draw definitive conclusions with regards to the influence of exercise on fracture incidence.

8. Summary

Exercise is a vital strategy in the prevention and management of osteoporosis, if appropriately prescribed. For the healthy individual whose goal is to prevent osteoporosis, lifelong exercise including regular, brief, weight-bearing, high-impact exercise and high intensity PRT is recommended. Although the optimal dose of exercise for bone health and fracture prevention is yet to be fully determined from human trials, a minimum of two sessions of PRT, four to seven sessions of impact activities, and balance training, as described in Table 1, are recommended. It is also recommended that a variety of activities are undertaken, so the skeleton continues to be exposed to unfamiliar patterns of loading. Adequate calcium and vitamin D will complement exercise programs for musculoskeletal health and function. For the high-risk individual with established osteoporosis and increased risk of fracture, falls prevention programs with a focus on balance and mobility training and high intensity PRT are essential. High load PRT and moderate impact loading may not only improve bone mass and reduce kyphosis, but be safe and well-tolerated in older adults with low bone mass. Ongoing supervision is required for individuals at high risk of low trauma fracture and those unaccustomed to high intensity exercise. Correct technique, particularly for exercises loading the spine, is imperative to

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Table 3
Potential risks and management strategies for the current exercise recommendations.

Potential risk	Preventive strategy
Injurious fall	Prescribe balance training prior to aerobic training if gait and balance are impaired Prescribe progressive resistance training for sarcopenia and muscle weakness Optimise lighting, visual aids, safety of exercise environment, climate conditions, footwear, judgment Review medications for agents which may cause falls, postural hypotension, or altered central nervous system function
Spinal compression fractures	Avoid loaded spine flexion Avoid twisting movements of the spine Emphasise good sitting and standing posture, including scapular retraction and depression and back extension exercises Sit with feet slightly elevated off floor to maintain core muscle contraction and back extensor muscle activation during sitting/sedentary activities Avoid or modify sports/activities involving spinal flexion (bowling, biking, golf, gardening, vacuuming) Bend knees rather than spine to pick up or reach low objects
Dislocation of total hip prosthesis	Avoid internal rotation and flexion of the hip
Pain from osteoarthritis	Use low-impact, high-intensity exercises (such as weight lifting) rather than high-impact exercises (jumping, hopping)
Pain from hip fracture, spinal osteoporosis, or old compression fractures	Rule out new fractures or dislocation of surgical prostheses Wait 6 wk after surgical repair of fractured femur for PRT or impact training, or until healing evident on radiographic examination Brace or support spine during exercise if needed Use analgesia or local pain relieving techniques (heating, massage, etc.)

Adapted from Fiatarone Singh.[79]

avoid increasing the risk of vertebral fracture. Individuals should be screened for other fall risk factors and counselled with respect to methods to reduce those risks in their everyday lives.

References

1. *Osteoporosis Prevention D, and Therapy. NIH Consensus Statement Online*, 2000.
2. WHO. *WHO Study Group on Assessment of Fracture Risk and its Application to Screening for Postmenopausal Osteoporosis. Geneva*, 1994.
3. Marshall D, Johnell O, Wedel H. Meta-analysis of how well measures of bone mineral density predict occurrence of osteoporotic fractures. *BMJ* 1996; 312(7041):1254–1259.
4. Sanders KM, Nicholson GC, Watts JJ et al. Half the burden of fragility fractures in the community occur in women without osteoporosis. When is fracture prevention cost-effective? *Bone* 2006; 38(5):694–700.
5. Nguyen T, Sambrook P, Kelly P et al. Prediction of osteoporotic fractures by postural instability and bone density. *BMJ* 1993; 307(6912):1111–1115.
6. Watts J, Abimanyi-Ochom J, Sanders KM. *Osteoporosis Costing All Australians. A New Burden of Disease Analysis – 2012 to 2022. Sydney*, 2013.
7. Martyn-St James M, Carroll S. Meta-analysis of walking for preservation of bone mineral density in postmenopausal women. *Bone* 2008; 43(3):521–531.
8. Taaffe DR, Snow-Harter C, Connolly DA et al. Differential effects of swimming versus weight-bearing activity on bone mineral status of eumenorrheic athletes. *J Bone Miner Res* 1995; 10(4):586–593.
9. Rector RS, Rogers R, Ruebel M et al. Participation in road cycling vs running is associated with lower bone mineral density in men. *Metabolism* 2008; 57(2):226–232.
10. Hatori M, Hasegawa A, Adachi H et al. The effects of walking at the anaerobic threshold level on vertebral bone loss in postmenopausal women. *Calcif Tissue Int* 1993; 52(6):411–414.
11. Borer KT, Fogleman K, Gross M et al. Walking intensity for postmenopausal bone mineral preservation and accrual. *Bone* 2007; 41(4):713–721.
12. Ma D, Wu L, He Z. Effects of walking on the preservation of bone mineral density in perimenopausal and postmenopausal women: a systematic review and meta-analysis. *Menopause* 2013; 20(11):1216–1226.
13. Sherrington C, Tiedemann A, Fairhall N et al. Exercise to prevent falls in older adults: an updated meta-analysis and best practice recommendations. *N S W Public Health Bull* 2011; 22(3–4):78–83.
14. Lanyon LE, Rubin CT. Static vs dynamic loads as an influence on bone remodelling. *J Biomech* 1984; 17(12):897–905.
15. O'Connor JA, Lanyon LE, MacFie H. The influence of strain rate on adaptive bone remodelling. *J Biomech* 1982; 15(10):767–781.
16. Rubin CT, Lanyon LE. Regulation of bone mass by mechanical strain magnitude. *Calcif Tissue Int* 1985; 37(4):411–417.
17. Rubin CT, Lanyon LE. Regulation of bone formation by applied dynamic loads. *J Bone Joint Surg Am* 1984; 66(3):397–402.
18. Robling AG, Burr DB, Turner CH. Recovery periods restore mechanosensitivity to dynamically loaded bone. *J Exp Biol* 2001; 204(Pt 19):3389–3399.
19. Lanyon LE. Using functional loading to influence bone mass and architecture: objectives, mechanisms, and relationship with estrogen of the mechanically adaptive process in bone. *Bone* 1996; 18(1 (Suppl.)):37S–43S.
20. Snow CM, Williams DP, LaRiviere J et al. Bone gains and losses follow seasonal training and detraining in gymnasts. *Calcif Tissue Int* 2001; 69(1):7–12.
21. Alfredson H, Nordstrom P, Lorentzon R. Bone mass in female volleyball players: a comparison of total and regional bone mass in female volleyball players and nonactive females. *Calcif Tissue Int* 1997; 60(4):338–342.
22. Bagur-Calafat C, Farrerons-Minguella J, Girabent-Farres M et al. The impact of high level basketball competition, calcium intake, menses, and hormone levels in adolescent bone density: a three-year follow-up. *J Sports Med Phys Fitness* 2015; 55(1–2):58–67.
23. Matthews BL, Bennell KL, McKay HA et al. Dancing for bone health: a 3-year longitudinal study of bone mineral accrual across puberty in female non-elite dancers and controls. *Osteoporos Int* 2006; 17(7):1043–1054.
24. Georgeson EC, Weeks BK, McLellan C et al. Seasonal change in bone, muscle and fat in professional rugby league players and its relationship to injury: a cohort study. *BMJ Open* 2012; 2(6).
25. Tsuzuku S, Ikegami Y, Yabe K. Effects of high-intensity resistance training on bone mineral density in young male powerlifters. *Calcif Tissue Int* 1998; 63(4):283–286.
26. Kontulainen S, Sievanen H, Kannus P et al. Effect of long-term impact-loading on mass, size, and estimated strength of humerus and radius of female racquet-sports players: a peripheral quantitative computed tomography study between young and old starters and controls. *J Bone Miner Res* 2003; 18(2): 352–359.
27. Slemenda CW, Johnston CC. High intensity activities in young women: site specific bone mass effects among female figure skaters. *Bone Miner* 1993; 20(2):125–132.
28. Behringer M, Gruetzner S, McCourt M et al. Effects of weight-bearing activities on bone mineral content and density in children and adolescents: a meta-analysis. *J Bone Miner Res* 2014; 29(2):467–478.
29. Kelley GA, Kelley KS, Kohrt WM. Exercise and bone mineral density in premenopausal women: a meta-analysis of randomized controlled trials. *Int J Endocrinol* 2013:741639.
30. Zhao R, Zhao M, Xu Z. The effects of differing resistance training modes on the preservation of bone mineral density in postmenopausal women: a meta-analysis. *Osteoporos Int* 2015; 26(5):1605–1618.
31. Kelley GA, Kelley KS, Kohrt WM. Exercise and bone mineral density in men: a meta-analysis of randomized controlled trials. *Bone* 2013; 53(1):103–111.
32. Kelley GA, Kelley KS, Kohrt WM. Effects of ground and joint reaction force exercise on lumbar spine and femoral neck bone mineral density in postmenopausal women: a meta-analysis of randomized controlled trials. *BMC Musculoskelet Disord* 2012; 13:177.
33. Allison SJ, Poole KE, Treece GM et al. The influence of high-impact exercise on cortical and trabecular bone mineral content and 3D distribution across the proximal femur in older men: a randomized controlled unilateral intervention. *J Bone Miner Res* 2015; 30(9):1709–1716.
34. Warden SJ, Fuchs RK, Castillo AB et al. Exercise when young provides lifelong benefits to bone structure and strength. *J Bone Miner Res* 2007; 22(2):251–259.
35. Warden SJ, Mantila Roosa SM, Kersh ME et al. Physical activity when young provides lifelong benefits to cortical bone size and strength in men. *Proc Natl Acad Sci U S A* 2014; 111(14):5337–5342.
36. Polidoulis I, Beyene J, Cheung AM. The effect of exercise on pQCT parameters of bone structure and strength in postmenopausal women – a systematic review and meta-analysis of randomized controlled trials. *Osteoporos Int* 2012; 23(1):39–51.
37. Kerr D, Morton A, Dick I et al. Exercise effects on bone mass in postmenopausal women are site-specific and load-dependent. *J Bone Miner Res* 1996; 11(2):218–225.
38. Martyn-St James M, Carroll S. Progressive high-intensity resistance training and bone mineral density changes among premenopausal women: evidence of discordant site-specific skeletal effects. *Sports Med* 2006; 36(8):683–704.
39. Steib S, Schoene D, Pfeifer K. Dose-response relationship of resistance training in older adults: a meta-analysis. *Med Sci Sports Exerc* 2010; 42(5):902–914.

40. Vainionpaa A, Korpelainen R, Vihriala E et al. Intensity of exercise is associated with bone density change in premenopausal women. *Osteoporos Int* 2006; 17(3):455–463.
41. Allison SJ, Folland JP, Rennie WJ et al. High impact exercise increased femoral neck bone mineral density in older men: a randomised unilateral intervention. *Bone* 2013; 53(2):321–328.
42. Niu K, Ahola R, Guo H et al. Effect of office-based brief high-impact exercise on bone mineral density in healthy premenopausal women: the Sendai Bone Health Concept Study. *J Bone Miner Metab* 2010; 28(5):568–577.
43. Bailey CA, Brooke-Wavell K. Optimum frequency of exercise for bone health: randomised controlled trial of a high-impact unilateral intervention. *Bone* 2010; 46(4):1043–1049.
44. Babatunde OO, Forsyth JJ, Gidlow CJ. A meta-analysis of brief high-impact exercises for enhancing bone health in premenopausal women. *Osteoporos Int* 2012; 23(1):109–119.
45. Bassey EJ, Rothwell MC, Littlewood JJ et al. Pre- and postmenopausal women have different bone mineral density responses to the same high-impact exercise. *J Bone Miner Res* 1998; 13(12):1805–1813.
46. Snow CM, Shaw JM, Winters KM et al. Long-term exercise using weighted vests prevents hip bone loss in postmenopausal women. *J Gerontol A: Biol Sci Med Sci* 2000; 55(9). M489–491.
47. Marques EA, Mota J, Carvalho J. Exercise effects on bone mineral density in older adults: a meta-analysis of randomized controlled trials. *Age (Dordr)* 2012; 34(6):1493–1515.
48. Engelke K, Kemmler W, Lauber D et al. Exercise maintains bone density at spine and hip EFOPS: a 3-year longitudinal study in early postmenopausal women. *Osteoporos Int* 2006; 17(1):133–142.
49. Kukuljan S, Nowson CA, Bass SL et al. Effects of a multi-component exercise program and calcium-vitamin-D3-fortified milk on bone mineral density in older men: a randomised controlled trial. *Osteoporos Int* 2009; 20(7):1241–1251.
50. Weeks BK, Beck BR. The BPAQ:X a bone-specific physical activity assessment instrument. *Osteoporos Int* 2008; 19(11):1567–1577.
51. Woo J, Hong A, Lau E et al. A randomised controlled trial of Tai Chi and resistance exercise on bone health, muscle strength and balance in community-living elderly people. *Age Ageing* 2007; 36(3):262–268.
52. Duckham RL, Masud T, Taylor R et al. Randomised controlled trial of the effectiveness of community group and home-based falls prevention exercise programmes on bone health in older people: the ProAct65+ bone study. *Age Ageing* 2015; 44(4):573–579.
53. Gillespie LD, Robertson MC, Gillespie WJ et al. Interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev* 2012; 9:CD007146.
54. Chu YH, Tang PF, Peng YC et al. Meta-analysis of type and complexity of a secondary task during walking on the prediction of elderly falls. *Geriatr Gerontol Int* 2013; 13(2):289–297.
55. Silsupadol P, Shumway-Cook A, Lugade V et al. Effects of single-task versus dual-task training on balance performance in older adults: a double-blind, randomized controlled trial. *Arch Phys Med Rehabil* 2009; 90(3):381–387.
56. Sinaki M, Itoi E, Wahner HW et al. Stronger back muscles reduce the incidence of vertebral fractures: a prospective 10 year follow-up of postmenopausal women. *Bone* 2002; 30(6):836–841.
57. Greig AM, Briggs AM, Bennell KL et al. Trunk muscle activity is modified in osteoporotic vertebral fracture and thoracic kyphosis with potential consequences for vertebral health. *PLOS ONE* 2014; 9(10):e109515.
58. Hernandez CJ, Beaupre GS, Carter DR. A theoretical analysis of the relative influences of peak BMD, age-related bone loss and menopause on the development of osteoporosis. *Osteoporos Int* 2003; 14(10):843–847.
59. Weeks BK, Beck BR. Are bone and muscle changes from POWER PE, an 8-month in-school jumping intervention, maintained at three years? *PLOS ONE* 2012; 7(6):e39133.
60. Winters KM, Snow CM. Detraining reverses positive effects of exercise on the musculoskeletal system in premenopausal women. *J Bone Miner Res* 2000; 15(12):2495–2503.
61. Wilsgaard T, Emaus N, Ahmed LA et al. Lifestyle impact on lifetime bone loss in women and men: the Tromso Study. *Am J Epidemiol* 2009; 169(7):877–886.
62. Karlsson MK, Linden C, Karlsson C et al. Exercise during growth and bone mineral density and fractures in old age. *Lancet* 2000; 355(9202):469–470.
63. Kemmler W, Bebenek M, Kohl M et al. Exercise and fractures in postmenopausal women. Final results of the controlled Erlangen Fitness and Osteoporosis Prevention Study (EFOPS). *Osteoporos Int* 2015; 26(10):2491–2499.
64. Williams MA, Haskell WL, Ades PA et al. Resistance exercise in individuals with and without cardiovascular disease: 2007 update: a scientific statement from the American Heart Association Council on Clinical Cardiology and Council on Nutrition, Physical Activity, and Metabolism. *Circulation* 2007; 116(5):572–584.
65. American College of Sports Medicine Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med Sci Sports Exerc* 1998; 30(6):975–991.
66. Farlie MK, Robins L, Keating JL et al. Intensity of challenge to the balance system is not reported in the prescription of balance exercises in randomised trials: a systematic review. *J Physiol* 2013; 59(4):227–235.
67. Tiedemann A, Sherrington C, Close JC et al. Exercise and Sports Science Australia position statement on exercise and falls prevention in older people. *J Sci Med Sport* 2011; 14(6):489–495.
68. Watson SL, Weeks BK, Weis LJ et al. Heavy resistance training is safe and improves bone, function, and stature in postmenopausal women with low to very low bone mass: novel early findings from the LIFTMOR trial. *Osteoporos Int* 2015; 26(12):2889–2894.
69. Giangregorio LM, Papaioannou A, Macintyre NJ et al. Too Fit To Fracture: exercise recommendations for individuals with osteoporosis or osteoporotic vertebral fracture. *Osteoporos Int* 2014; 25(3):821–835.
70. Singh NA, Quine S, Clemson LM et al. Effects of high-intensity progressive resistance training and targeted multidisciplinary treatment of frailty on mortality and nursing home admissions after hip fracture: a randomized controlled trial. *J Am Med Dir Assoc* 2012; 13(1):24–30.
71. Winters-Stone KM, Snow CM. Musculoskeletal response to exercise is greatest in women with low initial values. *Med Sci Sports Exerc* 2003; 35(10):1691–1696.
72. Multanen J, Nieminen MT, Hakkinen A et al. Effects of high-impact training on bone and articular cartilage: 12-month randomized controlled quantitative MRI study. *J Bone Miner Res* 2014; 29(1):192–201.
73. Daly RM, Duckham RL, Gianoudis J. Evidence for an interaction between exercise and nutrition for improving bone and muscle health. *Curr Osteoporos Rep* 2014; 12(2):219–226.
74. Bischoff-Ferrari HA. Vitamin D and fracture prevention. *Rheum Dis Clin North Am* 2012; 38(1):107–113.
75. Bolland MJ, Grey A, Reid IR. Differences in overlapping meta-analyses of vitamin D supplements and falls. *J Clin Endocrinol Metab* 2014; 99(11):4265–4272.
76. Moayyeri A. The association between physical activity and osteoporotic fractures: a review of the evidence and implications for future research. *Ann Epidemiol* 2008; 18(11):827–835.
77. Howe TE, Shea B, Dawson LJ et al. Exercise for preventing and treating osteoporosis in postmenopausal women. *Cochrane Database Syst Rev* 2011;(7):CD000333.
78. Kemmler W, Haberle L, von Stengel S. Effects of exercise on fracture reduction in older adults: a systematic review and meta-analysis. *Osteoporos Int* 2013; 24(7):1937–1950.
79. Fiatarone Singh MA. Exercise and bone health, in *Nutrition and Bone Health*, 2nd ed., Holick MF, Neeves JW, editors, New York, Humana Press, 2014.

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