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The Role of Physical Activity in Bone Health: A New Hypothesis to Reduce Risk of Vertebral Fracture

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Locomotion has always been a major criterion for human survival. Thus, it is no surprise that science supports the dependence of bone health on weight-bearing physical activities. "Bone, to be maintained, needs to be mechanically strained—within its biomechanical limits" [1].

Musculoskeletal challenges of aging

Bone loss and sarcopenia of aging cause an imbalance in the body's musculoskeletal ability to withstand extensive mechanical strain. A mechanical strain to the skeletal structure can be as low as gravity alone and as high as the impact of a moving, energized body part as it contacts a hard floor. The point of no return for fracture is defined by the quality of the bone and supportive soft tissues of the musculoskeletal structure.

Bone loss related to aging is more challenging for the female skeleton than the male skeleton. In one study comparing the ash weight of vertebral bodies (L3) in the cadavers of men and women aged 18 to 96 years, women had significantly lower ash weight than men of the same age [2]. Sarcopenia of aging affects women more than men because women start life with less muscle strength [3].

The process of bone remodeling affects bone loss more from metabolically hyperactive trabecular bone than cortical bone at menopause. The result is 47% bone loss from the spine during a woman's life [4]. The most significant bone loss occurs between ages 50 and 58 years, after sudden gonadal atrophy at menopause. In men, age-related axial bone loss is

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approximately 30% throughout life, and occurs more gradually because no sudden reduction in reproductive hormones occurs. The appendicular bone loss of aging is also less in men (15%) than in women (30%) [5]. In boys and girls, axial and appendicular muscle strength is approximately the same until age 10 years, when a discrepancy begins to develop (Fig. 1) [3].

Back extensor strength (BES) in women at different decades of life ranges from 54% to 76% of the strength in men (Fig. 2) [6]. This difference in BES between the genders decreases with age. By age 90, men have lost 64% of their maximal BES and women have lost 50% [6]. Sarcopenia of aging affects type II (fast twitch) muscle fibers more than type I fibers. This process expands the ratio of type I motor neuron units at the expense of the type II fibers [7]. The result of these changes is smaller, weaker muscles. Clinically, the consequence is a decrease in the protective role of muscles in locomotion and musculoskeletal health. The loss of muscle strength and bone mass creates more challenges for women than men, because women start life with less bone and muscle mass. In addition, other age-related spinal changes, such as facet arthropathies and reduction of resilience in intervertebral disks, decrease spinal flexibility [8] and can subsequently increase risk for vertebral fracture.

A person who has a fear of falling tends to decrease locomotion and weight-bearing physical activities. In one study, healthy community-dwelling subjects who had osteoporosis had a significantly higher perceived risk for falls than control subjects [9]. The fact that risk for falls increases with aging is well known [10,11]. Participation in a moderate level of physical activity is a significant component of physical and mental health in older adults and can decrease death rate; however, loss of bone and muscle mass may limit their choice of physical activity. Limitation of locomotion

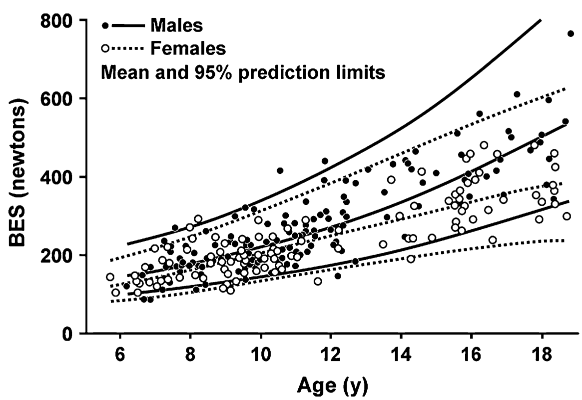

Fig. 1. Correlation of back extensor strength (BES) and age in 246 healthy children (137 boys and 109 girls). (*From* Sinaki M, Limburg PJ, Wollan PC, et al. Correlation of trunk muscle strength with age in children 5 to 18 years old. Mayo Clin Proc 1996;71(11):1047–54. Used with permission of Mayo Foundation for Medical Education and Research.)

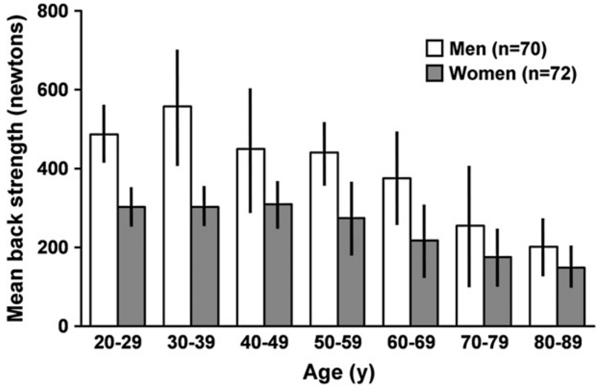

Fig. 2. Back extensor strength in men and women during the third through ninth decades. (*From* Sinaki M, Nwaogwugwu NC, Phillips BE, et al. Effect of gender, age, and anthropometry on axial and appendicular muscle strength. Am J Phys Med Rehabil 2001;80(5):330–8; with permission.)

is inevitable, whether it is caused by central nervous system disorders or the musculoskeletal changes of aging, which usually adds to premature frailty of aging. Risk for falls may increase because of extraskeletal or intraskeletal factors, which are listed in Box 1.

Maintaining biomechanical competence of bone

Proper mechanical loading can increase osteoblastic activity and the rate of bone formation, but its mechanism is not fully understood [12,13]. One study showed that job-related physical activity correlated significantly with bone mineral density of the spine (Fig. 3) [14]. This study showed that individuals working in a medical center who performed weight lifting at their jobs had greater bone mineral density than those engaged in a sedentary job. Some studies that used interventions to improve bone mass in humans did not show a significant increase in bone mass of the spine with weight-training exercises for the back extensor muscles [15,16]. This unexpected result may be attributed to the low intensity of the exercise program, the method used to expose the bone to load, the subject's compliance, or, perhaps, the genetic coding of the bone itself. However, the benefit of exercise on bone should not always be measured based on increased bone mineral density; the resulting changes in bone structure are important in increasing bone strength. One study in animals showed that mechanical loading improved bone strength by reshaping bone structure without increasing bone mineral density [17].

Preventing bone fracture, whether through increasing bone mineral density or reshaping the trabeculae, is the objective of clinical intervention.

Box 1. Factors that contribute to risk of falls

Extrinsic

Environmental
- Physical obstacles
- Slippery floor
- Uneven surfaces
- Poor illumination
- Ill-defined stairs
- Pets
- Icy sidewalks

Extraskeletal
- Inappropriate footwear
- Obstructive clothing

Intrinsic

Lower-extremity weakness (neurogenic or myopathic)
Balance disorder (eg, vestibular changes, peripheral neuropathy, hyperkyphosis)
Visual impairment, use of bifocals
Cognitive decline
Decreased coordination (eg, cerebellar degeneration)
Postural changes, imbalance, gait unsteadiness
Gait apraxia
Reduced muscle strength
Reduced flexibility
Respiratory difficulty (eg, orthopnea)
Postural hypotension
Cardiovascular deconditioning
Iatrogenically reduced alertness

Modified from Sinaki M. Prevention of hip fracture: physical activity. In: Senile osteoporosis. Ringe JD, Meunier JP, editors. Stuttgart: Georg Thieme Verlag Publications; 1996. p. 99–115; and Sinaki M. Falls, fractures, and hip pads. Curr Osteoporos Rep 2004;2(4):131–7; with permission.

Most current medical literature focuses on the role of exercise in improving bone mass. In a recent long-term follow-up of a controlled trial, however, improved back muscle strength was shown to reduce the risk for vertebral fractures several years after the exercise program was discontinued [18]. The results of this study prompted a new hypothesis that perhaps the exercises to decrease vertebral fracture should be different from loading exercises to increase bone mineral density in the upper and lower extremities.

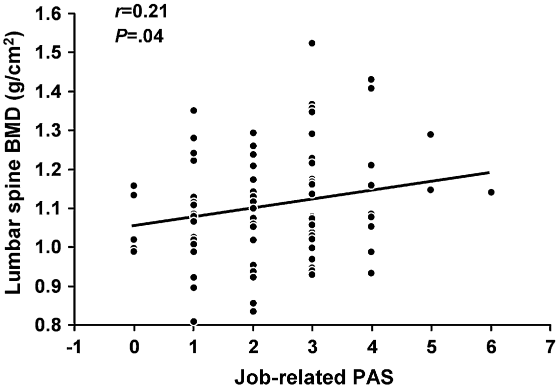

Fig. 3. Physical activity score (PAS) significantly correlated with spinal bone mineral density (BMD). (*From* Sinaki M, Fitzpatrick LA, Ritchie CK, et al. Site-specificity of bone mineral density and muscle strength in women: job-related physical activity. Am J Phys Med Rehabil 1998;77(6):470–6; with permission.)

Choosing a proper physical activity program

Determining how to perform osteogenic exercises, especially in individuals who have osteopenia or osteoporosis, without exceeding the bone's biomechanical competence always poses a dilemma and must be done under medical supervision. Not all exercises are osteogenic. Several studies support the positive effect of physical activity on the maintenance of musculoskeletal health [14,18,19]. However, the significance of the type of exercise and the exercise techniques on bone mass were investigated in recent decades, and the studies have added further information. Before 1980, spinal flexion exercises were popular for managing back pain related to vertebral fractures. The possible logic behind prescribing spinal flexion exercises was to stretch the paraspinal muscles that are in painful cocontraction while guarding the painful, fractured vertebral bodies [20]. Flexing the spine might have made scientific sense initially, but considering that these exercises flexed and compressed the osteoporotic spine, which was already biomechanically compromised, made no common sense. The clinical study, which was conducted to clarify the investigators' clinical impression, supported the fact that flexion of the osteoporotic spine would result in more vertebral compressions or fractures (Fig. 4) [20,21]. In this study, 59 women aged 49 to 60 years (mean age, 56 years) with postmenopausal spinal osteoporosis and back pain were divided into four groups. One group performed spinal extension exercises (not hyperextension), one group performed spinal flexion exercises, one group performed a combination of spinal extension and flexion exercises, and one group received only heat and massage with no prescribed exercise. All groups received instructions for proper posture principles. Follow-up time varied from 1 to 6 years (means for the groups, 1.4–2 years)

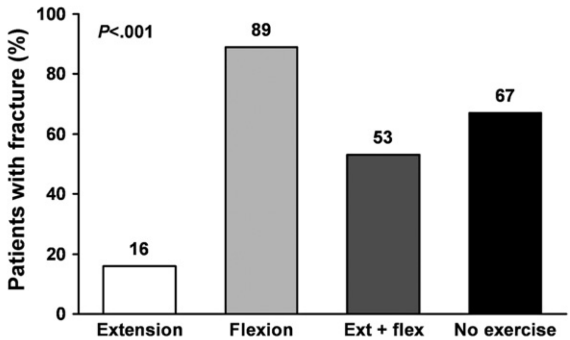

Fig. 4. Percentage of patients who experienced fracture after spinal extension exercise, spinal flexion exercise, a combination of extension and flexion (Ext + flex) exercise, and no exercise. (*Data from* Sinaki M, Mikkelsen BA. Postmenopausal spinal osteoporosis: flexion versus extension exercises. Arch Phys Med Rehabil 1984;65(10):593–6.)

dependent on the occurrence of increased back pain, which indicated a need for follow-up radiographic evaluation. The extension group had a longer period before follow-up. All subjects underwent spine radiographic studies before initiation of the treatment program and at follow-up, when any further wedging or compression fractures, or both, were recorded. Comparisons of the baseline and follow-up radiographs showed additional fractures in 16% of subjects in the extension group, 89% in the flexion group, 53% in the extension and flexion group, and 67% in the group that had no prescribed exercises for treatment and was provided only heat and massage (see Fig. 4).

The difference between the spinal extension and spinal flexion groups was most significant ($P < .001$). The P values were also significant for the extension group versus the extension and flexion group ($P < .01$) and for the extension group versus the no-exercise group ($P < .01$). The result of this study was so surprisingly supportive of the author's clinical impression that exposing the osteoporotic spine to flexion exercises in a prospective study seemed unethical. Flexion of the spine has also been shown to increase intradiskal pressure [22], which can be transmitted to osteoporotic vertebral bodies anteriorly and result in vertebral wedging and fracture.

The conclusion that physical activity affects bone has been reported repeatedly; however, not all exercises affect bone and muscle in the same way. Osteogenicity depends on the type, intensity, and duration of the exercise performed. In addition, the type of exercise must differ according to the various spinal deformities or skeletal challenges.

Reducing the risk for vertebral fractures without increasing bone mass

In one study, the author and colleagues showed that bone mineral density of vertebral bodies and back strength were correlated [23]. Later, however, they found that resistive exercises that did not load the spine vertically could not increase the vertebral bone mass, although back extensor strength increased significantly (Fig. 5) [15]. Initially, the lack of increase in bone mineral density was disappointing, but they later learned that the long-term effect of these exercises was very promising and effective in reducing the risk for vertebral fractures [18]. Exercise can affect not only bone mass and muscle strength but also vertebral structure and the horizontal trabeculae, which may individually reduce the risk for vertebral fractures [18].

Osteogenicity and site specificity

The effect of physical activity on bone is site-specific. In young and old tennis players, the bone mineral density in the dominant humerus was reportedly up to 33% greater than in the nondominant humerus [24,25]. Weight lifters have been shown to have greater bone mineral density of the spine and femur than athletes who do aerobic activity [26]. Also, swimmers have been shown to have less bone mineral density of the femoral neck than sedentary people [27]. Although swimming exercises are not osteogenic in women, their effect on improving muscle strength and general fitness should not be minimized [28]. The correlation of muscle strength at various sites of the axial and appendicular skeleton with physical activity and aerobic capacity was assessed in one study of women aged 29 to 40 years [29]. This study showed that maximal oxygen uptake is not a valid marker for the level of daily weight-bearing physical activities.

Significance of mechanical loading of physical activity in bone health

In general, physical activity increases the competence of neuromuscular structures to reduce the risk for fracture. This effect is accomplished through

Fig. 5. Model showing the author's back-strengthening exercise with a backpack containing sandbag weights. (*From* Sinaki M, Wahner HW, Offord KP, et al. Efficacy of nonloading exercises in prevention of vertebral bone loss in postmenopausal women: a controlled trial. Mayo Clin Proc 1989;64(7):762–9. Used with permission of Mayo Foundation for Medical Education and Research.)

improvement in muscle strength, bone structure, and neuromuscular efficiency, thereby reducing the risk for falls [19]. In animal studies, the bone response to mechanical loading was proportional to the applied dose of load in cell and organ culture [30]. In human studies, the evaluation of this relationship has been hindered by a lack of proper technology. With the advancement in quantitative CT and MRI techniques, further research will help clarify these issues.

Mechanical stimulus initiates a chain of events that involves intracellular messengers. The subsequent effects on proper cellular coding can cause bone formation and increase bone mass [31]. Several studies on exercise have discovered more facts about effective exercises for managing bone health [19,27,32]. The effects of high strain from muscle contractions in non–weight-bearing exercises compared with weight-bearing exercises did not increase lumbar and femoral bone mass in eumenorrheic swimmers. In a finding of great interest, the study reported that the bone mineral density of the femoral neck and spine was significantly less in swimmers than in gymnasts but not different from that in control subjects [32,33].

Several studies report the effect of strengthening exercises on bone mass in postmenopausal women [16,20,34–36]. These reports substantiate the conclusion that bone mass is not the only factor in maintaining bone health; muscle strength is also important. Although physical exercises are needed at all stages of life, women at risk for fracture should initiate a specific exercise program rather than increase bone strain during their habitual physical activities [37]. For example, they should perform back strengthening exercises in a sitting or prone position, rather than lift heavy loads during gardening, cooking, or other strenuous homemaking activities.

Optimal physical activity for bone health

Optimal exercise programs differ according to an individual's cardiovascular health, bone density, muscle strength, and history of involvement in sports activity. The status of lower-extremity joints and neuromuscular health are also decisive factors in selecting an appropriate exercise program for patients. Considering these issues before recommending exercises increases the probability of adherence to the prescribed program. Prevention of falls also must be addressed, because frailty associated with osteoporosis increases the risk for fracture and the fear of participation in ambulatory activities. Musculoskeletal changes that increase spinal deformities, especially hyperkyphosis, may increase the risk for falls [38].

Muscular strength of the axial skeleton is important in preventing falls. The main axial support is provided by back extensors, hip muscle groups, and the quadriceps. One study showed that the risk for falls decreased when lower-extremity muscles were strengthened through resistance-training exercises [39]. Another study showed that improvement in back muscle strength increased the level of physical activity [9,40].

Prescribing optimal exercise programs is different from advising patients to stay physically active. Some physical activities may increase the risk for vertebral fracture rather than improve skeletal health. (Of these activities, the most well-documented is flexion of the osteoporotic spine with or without lifting a load with the upper extremities.) In addition, inducing flexion on an osteoporotic spine, even without loading the spine, may result in vertebral fracture (see Fig. 4) [21]. One study found that sarcopenia of aging affected the lower extremities more than the upper extremities [6]. This study in women showed that, over the decades of life, body mass index increased while muscle strength decreased significantly (Fig. 6). A gradual increase in the level of physical activity can increase muscle strength and thus improve lean body mass, which mainly consists of supportive skeletal muscles. However, extra body fat can decrease the risk for fracture in areas such as the hips by dispersing the energy of a fall-related impact.

Increasing the level of physical activity despite osteoporosis and pain

Osteoporosis-related back pain, whether chronic or acute, prevents participation in physical activities (Fig. 7) [9]. Further bone and muscle loss concomitantly occurs when immobility related to back pain persists. In addition, the pain-induced inhibition of contraction of back extensors results in overuse of spinal flexors that guard the spine, which may further contribute to hyperkyphosis. Physical therapeutic measures that facilitate the use of back extensors (eg, posture training with or without weighted kypho-orthosis) reduce back pain and immobility and increase the level of physical activity. A significant decrease in back pain and risk for falls and improvement in the level of physical activity have been achieved through the spinal proprioceptive extension exercise dynamic (SPEED) program ($P < .05$) [9]. In the

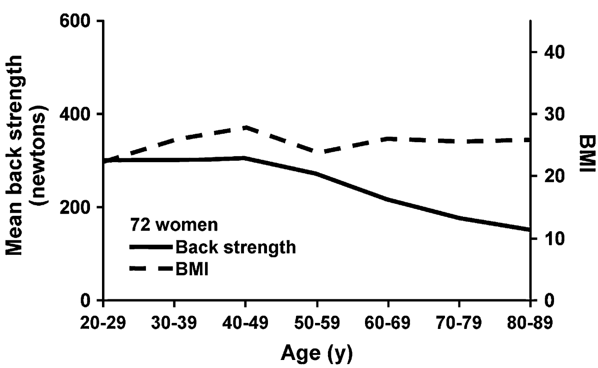

Fig. 6. Back extensor strength and body mass index (BMI) in women during the third through ninth decades. (*From* Sinaki M, Nwaogwugwu NC, Phillips BE, et al. Effect of gender, age, and anthropometry on axial and appendicular muscle strength. Am J Phys Med Rehabil 2001; 80(5):330–8; with permission.)

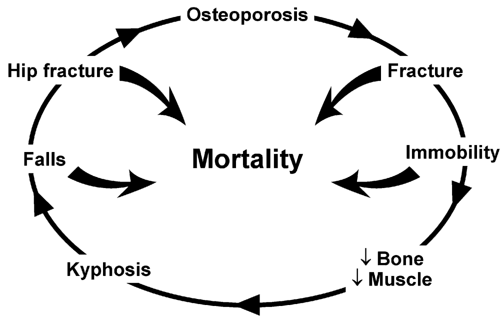

Fig. 7. “Circle of events” showing common events that can result in hip fracture and mortality.

SPEED program, joint proprioceptors are used to improve spine posture and balance disorder. Another issue is that prior fracture has been consistently associated with increased risk for subsequent fractures [41,42].

After compression fracture of vertebral bodies and its induced back pain, participation in physical activity decreases. To decrease painful contractions of the erector spinae muscles, a decrease is needed in the load over the anterior aspect of the spinal column and vertebral bodies and may be accomplished through the use of a back support. Initially, a rigid shell or brace may be considered, but most elderly patients who have spinal deformity do not tolerate them for more than a short time. If a patient has a spinal deformity, using a weighted kypho-orthosis with the weights positioned below the inferior angles of the scapulae unloads the spine in the more desired direction and thus improves the kinetics of the spine, rather than causing the spine immobilization that results from rigid bracing. This device may kinematically facilitate the use of the erector spinae muscles to protect the spine, because most compression fractures occur in the midthoracic and thoracolumbar junction and upper lumbar vertebral bodies. Kyphotic posture kinematically creates an angle for contracting the erector spinae muscles that is not advantageous.

Physical activity, whether it is in homemaking, job-related, or structured sports activities, correlates with improvement of muscle strength in the back and the upper and lower extremities according to the areas of the body involved in the activity [43,44]. Structured physical activity, such as a whole-body vibration program, has been shown to increase muscle strength, balance, and bone mineral density of the hip [45]. These exercise machines are newly available and must be evaluated further. The use of exercise machines that increase hip muscle strength (Fig. 8) contributes to improved body mechanics and body mass index [46]. A back-extension exercise program may improve posture and decrease risk for vertebral fracture and falls [9]. Back-extension strengthening exercises can be implemented with use of a progressive, resistive exercise program (see Fig. 5) [15]. In individuals who have osteoporosis, these exercises can be performed without applying weight

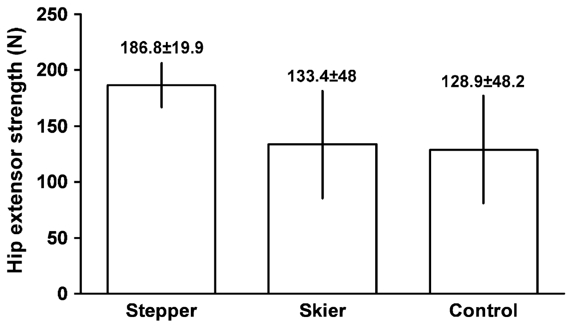

Fig. 8. Hip extensor strength was significantly higher in stepper group than in skier and control groups (stepper versus skier, $P = .03$; stepper versus control, $P = .03$; skier versus control, $P = .72$). Numbers at top of columns are mean ± SD. N, newton. (*From* Sinaki M, Canvin JC, Phillips BE, et al. Site specificity of regular health club exercise on muscle strength, fitness, and bone density in women aged 29 to 45 years. Mayo Clin Proc 2004;79(5):639–44. Used with permission of Mayo Foundation for Medical Education and Research.)

to the back (Fig. 9) [47]. Additionally, studies have shown that changes in the frequency of back-extension exercise or the repetition of weight lifting at each exercise session, or both, or changes in the exercise intensity may result in different outcomes [48].

In the postmenopausal stage, a woman's physical activity must consist of weight-bearing aerobic activities and safe weight-training exercises. Physical activity can decrease the prevalence of cardiovascular disease in postmenopausal women by 30% to 50% [49]. It is well known that physical activity contributes to the maintenance of cardiovascular fitness. Therefore, a 45- to 60-minute physical activity program must consist of cardiovascular exercise, such as walking (30 minutes); range-of-motion exercises combined with stretching; muscle strengthening (three times per week); and weight lifting (three times per week) [1]. Muscle strengthening consists of resistive exercises for the intended muscle groups, and weight

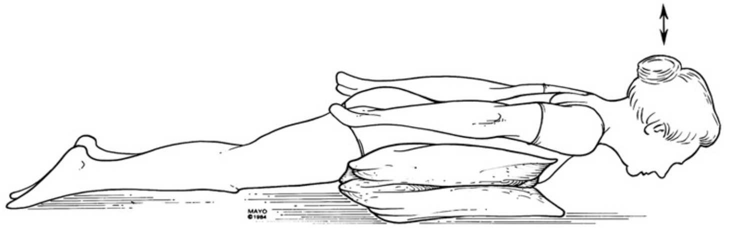

Fig. 9. Back-extension exercise performed in prone position with no added weight. (*From* Sinaki M, Grubbs NC. Back strengthening exercises: quantitative evaluation of their efficacy for women aged 40 to 65 years. Arch Phys Med Rehabil 1989;70(1):16–20. Used with permission of Mayo Foundation for Medical Education and Research.)

lifting consists of loading the spine or lower extremities with weights. Participating in a regular physical activity program consisting of weight-bearing, weight-training, and aerobic activities promotes good musculoskeletal and cardiovascular health.

Exercise after osteoporotic fracture

Physical rehabilitative measures play a key role in preventing further fracture. To improve a patient's level of physical activity after vertebral fracture, locomotion must be facilitated and axial muscle strength improved. Improvement in BES may increase the patient's level of physical activity [9,14]. The most successful physical activity and rehabilitative programs are those that are incorporated into the patient's usual daily ambulatory activities; they must be user-friendly and site-specific to back extensors without overdoing the strain on the spine or dependence on a specific exercise machine [1].

New hypothesis on the best exercise to reduce vertebral fracture risk

A study of the late effect of back-extension strengthening exercise after 8 years showed that vertebral fracture risk can be decreased through exercise (Fig. 10) [18,36]. However, exercises to decrease the risk for fractures of the

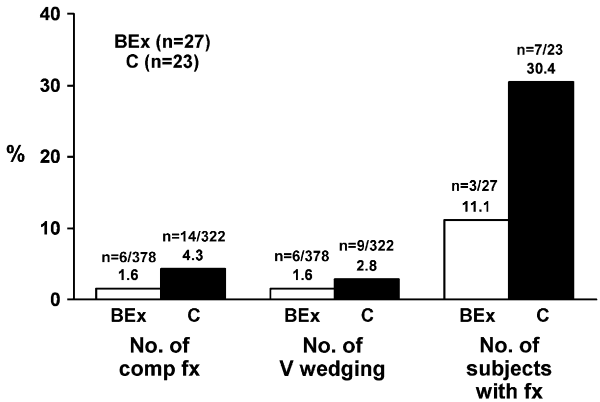

Fig. 10. At 10-year follow-up, the number of vertebral compression fractures (comp fx) was 14 (4.3%) of 322 vertebral bodies examined in the control (C) group and 6 (1.6%) of 378 vertebral bodies examined in the back exercise (BEx) group (χ^2 test, $P = .0290$). The number of subjects with vertebral fractures in the control group was three times greater than in the BEx group. The denominator represents the number of vertebral bodies that were evaluated using spinal radiographs at baseline and at 10-year follow-up; the nominator represents the number of vertebral bodies that were fractured or wedged on follow-up evaluation. V, vertebral. (*From* Sinaki M. Critical appraisal of physical rehabilitation measures after osteoporotic vertebral fracture. Osteoporos Int 2003;14(9):773–9. [erratum in: Osteoporosis Int 2006;17:1702]; with permission.)

spine are different from those to strengthen the upper extremities. The author's hypothesis is that back exercises performed in a prone position, rather than a vertical position, may have a greater effect on decreasing the risk for vertebral fractures without resulting in compression fracture. One can theorize that the risk for vertebral fractures can be reduced through improvement in the horizontal trabecular connection of vertebral bodies.

Summary

To be maintained, bone must be strained with a stimulus of specific magnitude and frequency. In postmenopausal osteopenia or osteoporosis, success depends on a combination of proper pharmacotherapy (especially adequate calcium and vitamin D supplementation) and biomechanical, bone-safe, osteogenic physical activity programs [50,51]. When the physical stimulus on bone is within a routine, daily range of physical activities, bone mass is neither lost nor increased. If the level of physical activity changes to one that is above or below the routine level, bone mass changes; if the change in activity puts more strain on bone, hypertrophy occurs. Severe repetitive loading strain that extends beyond the biomechanical competence of bone results in bone stress fracture, as observed in some soldiers, gymnasts, and long-distance runners [52,53]. If the loading physical activity is at an effective level that does not result in a stress fracture, it helps to increase bone mass. In postmenopausal women who have hormone deficiency, participation in very exertional weight-lifting exercises, such as lifting heavy objects, that applies loading beyond the biomechanical competence of bone can result in vertebral fracture. This is especially important since women with osteoporosis have lower back extensor strength [54]. Also, habitual, repetitive lifting and flexion of the spine may cause microfractures of vertebral bodies and gradual vertebral compressions that result in gradual loss of height. Therefore, flexion of the osteoporotic spine is not recommended because it strains the vertebral bodies anteriorly. If anterior loading on the vertebral bodies is beyond a woman's biomechanical competence, wedging and vertebral compression fractures can result during daily, not-so-innocent physical activities.

Successful, bone-safe physical activity for a challenged musculoskeletal status must be initiated under supervision to avoid injuries and improve adherence. The critical issue is adherence to a low to moderate level of physical activity in the postmenopausal stage.

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