Clinical Review: Current Concepts

Osteoporosis: Nonpharmacologic Management

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Osteoporosis is a chronic disorder of the skeleton causing increased bone fragility and fractures. In the second of our 3-part series, we discuss the beneficial effects of nonpharmacologic agents in the management of osteoporosis. We review the evidence supporting the use of exercise, whole-body vibration, hip protectors, low-intensity pulsed ultrasound, bracing, and vertebral augmentation procedures. The mechanism of action, precautions, and expected outcomes are discussed. Nonpharmacologic management of osteoporosis blends in very well with an overall exercise prescription. The nonpharmacologic interventions discussed are readily available and easy to implement. The use of such techniques demonstrates the important role of the physiatrist in the management of osteoporosis.

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EXERCISE

Galileo Galilei described the potential role of mechanical factors on bone health nearly 400 years ago. Pioneering research by Dr. Julius Wolff, who proposed Wolff’s law (ie, “form follows function”), and more recent research by Drs. Lent Johnson and Harold Frost, who proposed the mechanostat hypothesis [1], has enhanced our knowledge in this area. Currently, we are increasingly coming to appreciate the fact that bone is not an inanimate anatomic entity but a dynamic, living tissue liable to damage and resorption as well as capable of healing and growth.

Extensive research in this area has led to the understanding of the negative effects of unloading on the skeleton. Astronauts lose both trabecular and cortical bone at the rate of 1.5% per month and more in some instances [2]. Prolonged bed rest has been shown to increase bone resorption and decrease bone formation in normal subjects, causing a bone mineral density (BMD) decrease of 3.8% at the greater trochanter in 11 weeks. This finding is significant because the normal rate of bone loss is about 3% per decade for cortical bone and 7%-11% per decade for trabecular bone [2].

The risk of fracture is influenced by key factors such as skeletal fragility, frequency and severity of falls, and tissue mass surrounding the skeleton [3]. In addition, other medical comorbidities may increase the risk independently or by influencing these factors. This phenomenon has been explained by engineering principles such as the factor of risk, which is the ratio between applied load (on the skeleton) and fracture load (force required to fracture); exercise affects both variables. Decreasing the number of falls decreases the applied load. Improving neuromuscular function and BMD increases the fracture load [4].

Exercise has been shown to improve quality of life, physical function, pain, and vitality in osteoporotic and osteopenic postmenopausal women [5]. Physical activity improves balance, coordination, muscle strength, and reaction time [6]. Exercise was found to be beneficial in specific health and disease states. Patients who have previously undergone heart transplant surgery as well as women undergoing hormone-replacement therapy had increased BMD above that attainable by pharmacotherapy alone [7,8]. In a systematic review of 21 studies on this subject, Ernst [9] found that exercise could reduce the risk of osteoporosis and delay the physiological decrease of BMD. Ernst [9] concluded that regular exercise for women in all age groups was valuable for bone health. The authors of several studies have validated the beneficial effects of exercise on increasing BMD. Colletti et al [10] found that muscle-building exercise was associated with increased BMD at weight-bearing sites including the lumbar spine, trochanter, and neck of the femur. Similarly, increased cortical thickness of up to 45% was noted in the humerus of the dominant arm of tennis
players, further reinforcing the site-specific nature of the increase in bone density with exercise [11]. In a study of the effects of group exercise (3 times a week for 21 weeks) among osteoporotic and osteopenic postmenopausal women, Angin and Erden [12] found that 43.8% of the osteoporotic group and 23.5% of the osteopenic group had BMD improvements, leading to reclassification as osteopenic and normal, respectively.

However, several other studies have not been as encouraging. A meta-analysis of controlled exercise trials found that exercise caused a modest reduction in bone resorption, resulting in only a 1%-2% gain in BMD per year [13]. The authors of other studies concluded that exercisers did not have any BMD benefit over non-exercisers. Upon reviewing the literature on the effect of resistance training on premenopausal women, Singh et al [14] found that of the 12 studies reviewed, 4 found a positive effect, 7 found no effect, and one study actually found a negative effect. Thus although the deleterious effects of non-weight-bearing activity or microgravity on bone are well recognized, the literature exhibits some discordance regarding the beneficial role of exercise and the required loads, duration, and intensity needed to achieve BMD increase or other improvement in fracture risk. Also debated is the optimal age for such effects and whether benefits accrued through weight-bearing exercise continue after discontinuation of activity. Some of the potential reasons for the discrepancies in the literature are listed in the following sections.

Weakness of In Vivo Studies (11,15)

Limitations of Diagnostic Studies. Dual-energy x-ray absorptiometry has been used to measure bone mineral density changes after exercise. Although dual-energy x-ray absorptiometry is a good tool for assessing bone density, it only offers a 2-dimensional (areal) measure and not a true 3-dimensional (volumetric) evaluation of bone density. Thus although it is an efficacious tool for measuring the mineral content of bone, it may underestimate changes in mechanical properties. Newer technologies such as quantitative computed tomography are able to assess these changes more accurately, particularly finite element analysis of quantitative computed tomography images, which can predict bone strength.

Inconsistencies of the Exercise Intervention. Inconsistencies exist among studies regarding the duration of exercise and of follow-up (eg, months or years), the type of exercise studied (eg, weight bearing, jumping and bounding, swimming, running, and strength training), the type of sport studied (eg, tennis, soccer, gymnastics, and ice hockey), as well as the anatomic area tested; these inconsistencies have led to differences in outcome measures.

Lack of Blinding. It is not possible to conduct a randomized double-blinded trial, which is the gold standard for clinical studies, because neither researchers nor participants can be blinded to physical activity.

Selection of Subjects. The relationships among inactivity, poor bone health, and concomitant medical comorbidities are unclear.

Lack of Fracture End Points. The most significant clinical end point—that is, fracture—is not measured in most studies.

Potential Lazy Zone Phenomenon. Exercise that may stimulate muscle and cardiovascular systems does not necessarily cause similar effects in bone because of the “lazy zone” phenomenon (see the section “Concepts in Mechanical Effects on Bone”).

Concepts in Mechanical Effects on Bone

Bone strain is a measure of bone deformation and is a key determinant in the adaptive response of bone to loading. Strain magnitude and the rate of change in bone strain are positively related to increases in bone mass. Frost, in the “mechanostat theory,” has suggested that a minimum effective strain for both modeling and remodeling exists [16]. Bone strains that exceed the minimum effective strain for modeling will result in a net increase in bone mass, whereas strains falling below the minimum effective strain for remodeling will result in a decrease in bone mass. Bone strains falling between these threshold values generally will result in no net change in bone mass. This range of stimuli between the minimum effective strain for modeling (only above which bone accrual occurs) and the minimum effective strain for remodeling (below which bone loss occurs) is called the “lazy zone” [17]. Thus if a research subject exercises such that the strain on the bone is between these threshold values (within the so-called “lazy zone”), a significant accrual in bone may not occur, leading to the erroneous conclusion that exercise does not produce any significant changes in bone.

Several factors determine whether a stimulus is osteogenic, including strain magnitude, strain rate, strain distribution, strain gradients, cycle number, and strain frequency. Although a detailed description of individual determinants is beyond the scope of this review article, it is important to note that when formulating an exercise regimen, the aforementioned characteristics should be taken into account. For example, at high strain magnitudes, relatively few loading cycles are required to stimulate a bone response. Conversely, low-magnitude, high-frequency strains have been shown to be beneficial as well and could be used in frail patients. It is important to note that high-impact exercise is more beneficial than low-impact exercise [11]. Also, a threshold exists for loading cycles such that full response is triggered only after a certain number of loading cycles are accomplished [15]. The exact number of loading cycles in turn is determined by other
loading parameters, such as strain magnitude and peak strains achieved [15].

**Age and Reversibility**

Strong evidence suggests that exercise confers the most positive benefits on the skeleton before puberty. Indeed, the authors of several studies showed that girls who start impact training before menarche have better bone accrual than do those who start after menarche. However, exercise at any age (with no upper age limit) may have benefits that will potentially reduce fracture risk. A review of pooled data from 3 studies with a total of 566 community-dwelling women aged 80 years or older who received progressive muscle strengthening, balance retraining, and a walking plan demonstrated a reduction in the number of persons who sustained a fall during a 1-year period as well as a reduction in the number of injurious falls [18].

The reversibility of the accrued beneficial effects is debated. In a study by Vuori et al [19], 12 healthy young women underwent strength training 4 times a week for 1 year followed by 3 months of “detraining.” Although a significant increment in BMD was found in the exercise group, those beneficial effects decreased toward baseline values in the 3 months after cessation of training.

However, several studies that compared retired athletes with age-matched and body composition–matched control subjects concluded that the benefits of exercise during active years bestows increases in BMD that persist for at least 10-20 years [20]. In addition, studies in which subjects decreased their level of activity after retirement from active sports instead of completely stopping their activity retained increments in BMD as a result of the sports training. Thus it is reasonable to conclude that instead of complete cessation, continuation of exercise, albeit at a relatively decreased intensity, is still valuable for bone health [11].

**Mechanism of Action**

Few human studies exist to explain the proposed microarchitectural changes induced by exercise. However, experiments in a bovine model have demonstrated that exercise-induced changes include a smaller medullary cavity, a larger percentage of cortical bone area, increased BMD, and a trend toward a greater fracture force compared with those in the non-exercise group [21].

In an experimental group of running mice, BMD and cross-sectional area were greater in the running group after 6 months. Runners also showed greater breaking force and stiffness of the diaphysis and the femoral neck at 2 and 6 months. The authors concluded that the significant modulation of mechanical properties of the collagen network without any change in collagen content indicated that physical exercise improves properties of the collagen network in maturing bone [22]. You et al [23] demonstrated that mechanical loading stimulates osteocytes to release soluble factors that can inhibit the production of osteoclasts (whose function is to cause bone resorption), thereby decreasing bone turnover and thus preventing bone loss. Muscle forces transmitted to the bone during high-impact weight-bearing exercises also might explain the osteogenic response to exercise [24].

More studies are needed to further clarify the mechanisms underlying the beneficial effects of weight-bearing exercise.

**Role of Exercise in Fall Prevention**

Approximately one third of community dwellers older than 65 years and nearly half of institutionalized persons or persons older than 80 years fall each year. Almost half of those who fall will experience a repeat fall within the next year [25]. Although only 5%-10% of falls result in a fracture, 90% of hip fractures occur as a result of a fall [26].

Falls also are implicated in other osteoporotic fractures, such as wrist fractures. The annual risk of falling increases from approximately 1 in 5 in women aged 45-49 years to nearly half in women aged 85 years or older, along with one-third of elderly men [27]. Therefore a sound fall prevention program is integral to any successful osteoporotic fracture prevention program [28].

Such a program should focus on identifying the etiology of the falls, which could be related to the patient or the environment. Patient-specific causes include poor neuromuscular coordination; cognitive impairment; age-related changes in visual, proprioceptive, and vestibular systems; medications that might cause hypoglycemia, orthostasis, or altered mental status; or neurologic conditions such as stroke or Parkinson disease. Environmental factors include inappropriate shoes (shoes with increased heel height and decreased surface area between the sole and the floor are associated with a greater risk of falls), wet floors, poor lighting, loose scatter rugs, and improper bed height [25].

Physiatrists can play a significant role in decreasing patients’ fall risk by assessing these risk factors, by ameliorating them, and by prescribing gait-assistive devices when necessary. As previously mentioned, exercise also can decrease and potentially eliminate the risk of falls by increasing bone density, resulting in an overall diminished risk for fractures.

**The Exercise Prescription**

Any exercise prescription should incorporate 5 principles:

1. **Specificity**: Exercise should be site specific. Prevention of vertebral fractures has been reported with back-strengthening exercises, and lower extremity strengthening has been associated with fall prevention [29-31].

2. **Overload**: The “lazy zone” phenomenon should be considered and sufficient overload should be placed on the skeletal system over and above that required by the car-
diovascular and muscular systems. In fact, it is recommended that an exercise program should begin with loads of a relatively high magnitude (as long as the neuromuscular system and skeleton can tolerate them) to ensure that time is not lost in the lazy zone and that the skeleton gets adequate exposure at the desired load. This phenomenon is further demonstrated by studies that have shown that swimmers have a similar BMD to that of non-exercisers. Muscle forces on skeleton during swimming may not offset the decreased weight-bearing activity.

3. Reversibility: Reversibility is the potential for reversal of bone response once a stimulus is removed.

4. Initial values: Responses from bone are greatest when beginning levels are lower than average.

5. Diminishing returns: Once a given training level is achieved, further responses will be slow and of small magnitude.

Load magnitudes, rate of load application, load cycles, and number of exercise sessions per week should be individually tailored. Although running and jumping provide a similar load magnitude (2-4 X body weight), jumping has more consistently led to increases in BMD, because the loading rate (peak force/time to peak force) is significantly higher in jumping compared with running. Indeed, Kerr et al [32] demonstrated that lifting heavy weights a few times, some freely, was effective, whereas lifting lighter weights more often was not effective, although the improvement in muscle strength was similar.

Strength-training interventions have shown that high-intensity training (>80% of single repetition maximum) is more effective than is low- and moderate-intensity strength training. Thus an exercise program would start at a relatively high loading magnitude and at a moderate loading rate, specifically targeting the hips, spine, and wrist—sites that are most prone to osteoporotic fractures. In addition, exercises that strengthen the spine extensor should be incorporated into programs. In view of evidence suggesting that spine flexion-based exercises may be associated with increased vertebral fractures [29], such exercises should be avoided. Instead spine extension–based exercises that decrease the risk of fractures and improve the quality of life should be encouraged [30,33]. A strengthening program should be conducted along with a good balance training and fall prevention program. It is preferable that exercise programs be conducted in groups [34]. Even in studies in which BMD increases were not achieved, increases in muscular strength were found [35]; therefore strength training should be strongly encouraged. A lower extremity strength and balance training program has been recommended to decrease the incidence of falls [31].

As rehabilitation professionals, we understand the relationship between decreased function and disability [36]. Therefore exercise should be prescribed to prevent disability, decrease fractures, and improve overall health and well-being [37].

**WHOLE-BODY VIBRATION**

The initial basis for animal experiments using whole-body vibration (WBV) is the concept that trabecular bone adapts to its mechanical environment, also known as Wolff’s law [38]. High-frequency (30 Hz), low-magnitude (200 μ strain) vibration signals were reported to stimulate large increases in cortical bone in turkeys [39-41]. Subsequent experiments with other animal models have shown similar results [42]. Verschueren et al [43] reported that vibration training improved the isometric and dynamic muscle strength and BMD in humans. Rubin et al [44] demonstrated that with WBV for 1 year, postmenopausal patients who were most compliant with use of the vibrating plate had lower weight and some improvement in BMD. WBV has been shown to be feasible and beneficial in improving muscle performance, balance, and mobility in nursing home residents [45]. Hemiplegic patients had improved proprioception with WBV [46]. Evidence shows that WBV may counteract the effects of weightlessness and has beneficial effects, at least equivalent to locomotor training, in improving gait speed in patients with spinal cord injury [47]. The exact role of WBV in fracture healing is still debated [48].

**Mechanism of Action**

The scientific rationale for WBV is based on the “Daily Stress Stimulus Theory,” which proposes that if the daily stress stimulus on bone (considering both the magnitude and the number of cycles of loading applied to the skeleton) is greater than some target stimulus, a net bone gain will occur, and that if the daily stress stimulus is less than some target stimulus, a net bone loss will occur [49]. The theory also proposes that a high cycle number and low-magnitude stimulation may be sufficient for maintaining bone mass. WBV has an indirect effect on the bone tissue through amplification of signals by intramedullary pressure [50] or fluid flow through the extracellular spaces of the bone, thereby inducing mechanotransduction [51].

Stimulation of monosynaptic and polysynaptic neural pathways to generate a “tonic vibration reflex” (similar to the stretch reflex) is believed to cause cyclic contraction and relaxation of muscles for the duration of the vibration. The bone responds as a consequence of such applied forces generated by the muscle contractions. Also, WBV may have a positive influence on the endocrine system. Studies have demonstrated an increase in growth hormone and testosterone, both of which have an anabolic effect on bone after WBV [52].

It has been hypothesized that in addition to its salutary effect on osteoblast and osteocyte activity, WBV leads pro-
genitor cells to become bone cells rather than fat cells [53]. There are 6 determinants of the human skeletal system’s response to WBV: vibration direction (vertical versus oscillatory alternating), vibration frequency (in hertz), vibration magnitude measured as amplitude (displacement, in millimeters) and acceleration (in gravitational units, where 1.0 g = 9.81 m/s²), duration of the WBV, and body position/posture on the platform [52]. Regarding the direction of vibration, limited data are available to indicate which of the two directions—vertical versus oscillatory alternating—is more beneficial.

The internal organs of the body vibrate at a frequency range of approximately 5-20 Hz. Vibrations at this range are considered unsafe, and therefore frequencies of >25 to <75 Hz are considered safe, with most positive studies using a range of 25-45 Hz. High-frequency, high-magnitude vibrations (greater than 1 g) have several adverse effects, including low back pain after extended exposure; they also serve as a key etiologic factor in circulatory disorders such as Raynaud syndrome [54]. Several studies in which the authors demonstrated the safety and efficacy of WBV used a magnitude of 0.3 g. In terms of duration-intermittent cycles, repeated short vibration periods (2-20 min) separated by periods of quiescence are recommended. Finally, an erect posture during vibration is recommended for better transmissibility of forces to the hip and spine [52].

Safety Considerations

A WBV prescription should take into account the overall physical condition of the patient. Several contraindications to WBV exist, as shown in Table 1 [52]. Most of the adverse effects of vibration are related to occupational or transportation-related exposure [55] and to high-frequency, high-magnitude vibrations. As previously stated, low-magnitude vibrations in the 25- to 45-Hz frequency range have been found to be safe and effective. WBV is a relatively new modality with considerable potential for improving strength, balance, and BMD. However, among commercially available WBV machines, wide variability exists in the aforementioned parameters, most significantly frequency and magnitude. Even in experimental studies, wide ranges of frequency, magnitude, and posture have been used [47,52,56]. Compliance with WBV also has been variable. The exact place and most effective specifications of WBV for improving bone and decreasing fracture risk remain to be established.

Table 1. Contraindications to whole-body vibration (52)

- Kidney or bladder stones
- Arrhythmia
- Pregnancy
- Epilepsy
- Seizures
- Cancer
- Pacemaker
- Untreated orthostatic hypotension
- Recent implants (joint/corneal/cochlear, etc)
- Recent surgery
- Recently placed intrauterine devices or pins
- Acute thrombosis or hernia
- Acute rheumatoid arthritis
- Severe cardiovascular disease
- Severe diabetes
- Migraines

HIP PROTECTORS

Greenspan et al [57] reported that falling sideways as opposed to falling in other directions was independently associated with a greater risk of hip fracture. It has been postulated that the falling mechanism and the energy absorption of the trochanteric soft tissue are key determinants of hip fracture risk [58]. This supposition has led to the recommendation of devices to decrease the effects of impact at the time of a fall, thereby decreasing the fracture risk.

Hip protectors (HPs) essentially have 2 designs: those with a hard shell and those with a soft padding [59]. A third design incorporating both of these elements is also available. The hard shell design functions by distributing the force; energy is shunted by the hard shell of the pad away from the greater trochanter of the femur into the soft tissue surrounding it. The soft pad, on the other hand, absorbs energy within the protection pad, decreasing or potentially eliminating the impact forces. The hard shell HP, which has the most biomechanically advantageous design, is also the most uncomfortable [59]. However, HPs are effective only if they are able to cover the greater trochanter, especially the designs incorporating a hard shell [60].

Research is divided on the efficacy of HPs, with the authors of some studies reporting efficacy [61,62] and others reporting no benefit [63]. A Cochrane database review article [64] found that although studies with nursing home residents showed evidence of efficacy in fracture prevention, studies with elderly persons living in the community showed no benefit. It was concluded that acceptance and adherence by users of the protectors remained poor as the result of discomfort and nuisance. Although some researchers reported good results with good compliance [65], others have reported ineffectiveness despite adherence to HP use [66]. Fear of falling in itself has been identified as a risk factor for falls. Thus by providing confidence to the frail elderly [67], the HP may have a role in fall and fracture prevention. According to one study, only 41 persons need to use the HP for 1 year for one fracture to be prevented [62]. Villar et al [68] found that only approximately 30% of subjects in an elderly rest home complied with use of HPs after 3 months. Another 45% were willing to comply but gave up because of discomfort and poorly fitting devices. Caregiver motivation and involvement therefore appear to be crucial for improved compliance [69]. The attitude, education, and motivation of the staff may be another key factor in achieving good user
compliance [70]. Thus education of patients and caregivers is extremely important.

Nursing and residential home residents with cognitive impairment are at greater risk of hip fracture and should be targeted for HPs [71]. Some identified barriers to the use of HPs in long-term care facilities were that physicians did not think to prescribe them; expense; lack of evidence of benefit in this population; wearer discomfort; and removal of the HP by the wearer [72]. Such barriers need to be addressed if HP implementation strategies are to be successful in long-term care facilities. The introduction of a structured education program and the provision of free HPs in nursing homes increases the use of protectors and may reduce the number of hip fractures [73].

In a study by Sawka and colleagues [74], a cost analysis from the Canadian Ministry of Health perspective demonstrated that a strategy of providing HPs to all elderly Ontario nursing home residents could result in an overall mean cost savings of 6 million Canadian dollars in 1 year. Thus preemptive measures such as the use of HPs may result in a safe and financially sound option for persons at high risk for hip fractures. In the United States, Honkanen et al [75] used a hypothetical cohort of permanent nursing home residents aged 65 years and older without a previous hip fracture to show that 3 pairs of HPs replaced annually would result in a weighted average lifetime absolute risk reduction for hip fracture of 8.5%, with a net lifetime savings to Medicare of U.S. $223 per resident. When extrapolated to the nursing home population in the entire United States, this initiative could lead to a total savings of $136 million in the first year. However, the study assumes that the relative risk of fracture is less than or equal to 0.65 with HPs, or that adherence is greater than 42%. As stated previously, considerable debate exists regarding efficacy, and achieving adequate adherence may not be possible [75].

Finally, use of HPs is a low-risk intervention that potentially offers an almost immediate benefit in reducing fracture risk, unlike other interventions such as medications and exercise. On the basis of currently available evidence, its greatest utility is found in those who are at the greatest risk for a fracture, including the institutionalized elderly, frequent fallers, severely osteoporotic individuals, and those with cognitive impairment [65,67-69]. Increased adherence and comfort are key issues; education of both providers and patients may improve outcomes.

LOW-INTENSITY PULSED ULTRASOUND FOR FRACTURE HEALING

In the past 2 decades several different physical modalities have been approved for the management of non-unions and delayed unions. These modalities include implantable direct current stimulation, pulsed electromagnetic field capacitive coupling, and low-intensity ultrasound [76]. In this section we will focus on low-intensity pulsed ultrasound (LIPUS). Ultrasound is well recognized as a treatment modality in physical therapy [77] and in vascular medicine [78]. Recently LIPUS has evolved as a relatively safe treatment option to enhance fracture healing with successful applications in orthopedics [79] and dentistry [80].

Studies in humans [81] and animals [82] have established the efficacy of LIPUS. Delayed union and non-union of fractures are 2 of the most widely accepted conditions for which LIPUS has been shown to be effective, with overall success rate ranging from 67%-90%, depending on the bone under study [83]. In fresh fractures, LIPUS accelerated the fracture healing rate from 24% to 42%. Although continuous high-intensity (1.0 W/cm²) continuous-wave ultrasound signals may be harmful, low-intensity (30 mW/cm²) pulsed ultrasound signals (LIPUS) appear to promote accelerated fracture healing [84]. A meta-analysis found a mean difference in healing time of 64 days between the treatment and control groups after pulsed ultrasound [84]. Rats treated with LIPUS had greater bone mineral content, bone size, and greater mechanical strength compared with sham ultrasound–treated rats. Azuma et al [82], by using a similar animal model with a lower intensity of ultrasound, noted no changes in the hard callus area or bone mineral content at fracture sites. However, they did note that the maximum torque tolerated in the LIPUS-treated femur was significantly greater than that of control subjects. Although the exact mechanism of action is still uncertain, ultrasound may have a direct effect on several cell lines, including fibroblasts, chondrocytes, and osteoblasts that are involved in inducing cellular reparative processes of angiogenesis, chondrogenesis, and osteogenesis [82,85]. Increases in cell proliferation, protein synthesis, collagen synthesis, membrane permeability, integrin expression, and increased cytosolic Ca²⁺ levels also have been proposed as possible mechanisms of action [86]. Using power Doppler sonography, with and without contrast agent administration, Rawool et al [87] demonstrated increased vascularity around the fracture sites in treated dogs. Thus LIPUS is increasingly gaining acceptance as a safe and efficacious tool in expediting fracture healing. Cost appears to be a significant hurdle toward achieving wider acceptance [85].

BRACING

Bracing after an osteoporotic compression fracture allows for early mobilization and pain control. Because of low compliance, rigid body jackets or the Knight-Taylor orthoses have become less commonly prescribed. For lumbar fractures, a chairback brace is recommended, whereas cruciform anterior spinal hyperextension or Jewett braces are appropriate for persons with thoracic fractures [88].

Lumbar corsets have been shown to place additional stress on fractures at the thoracolumbar junction, and therefore their use is not recommended [89]. Posture training support
(a weighted kypho-orthosis) has demonstrated good compliance and resulted in statistically significant mean increases in back extensor strength [90]. Six-month use of a new lightweight spinal orthosis (available in the United States under the brand name Spinomed; Medi USA, Whitsett, NC) has been associated with a significant increase in back extensor strength, an increase in abdominal flexor strength, a decrease in angle of kyphosis, and a decrease in average pain and limitations in activities of daily living [91]. It is believed that stronger back muscles, by correcting the kyphosis and center of gravity, decrease postural sway and thus prevent falls and attendant nonvertebral fractures. Although it is conceivable that skin contact and friction can cause irritation and damage to the skin and should be closely monitored, brace treatment has not been shown to adversely affect bone mass at the spine and hip in children with idiopathic scoliosis [92]. We were unable to find studies in which the authors evaluated the effects of bracing on bone density in adults.

Spinal orthotics have a distinct role in the acute pain management of a vertebral fracture. However, despite evidence to support the benefits of spinal orthotics, they are grossly underused, so much so that we were unable to find articles about the prevalence of usage/underuse of spinal orthotics after a vertebral fracture. Perhaps the most realistic use for an orthotic is in the nursing home setting after a vertebral fracture, where compliance could be relatively easy because of the nursing care provided. Such orthotics could aid in the patients' ambulation and participation in therapy while reducing pain and thus the amount of pain medication needed. Significant benefits from wearing an orthotic for as few as 4 hours a day have been reported [90]. Patients derive pain relief when they wear the orthotics for specific activities, even after the fracture has healed [93]. Therefore bracing should be considered for hospitalized patients with acute vertebral fractures before discharge. When a patient with a vertebral fracture wears a brace, the resultant decrease in the load on the skeleton may be deleterious. However, the pain relief afforded by the brace may lead to improved ambulation and mobility, which may have overall salutary effects on the skeleton. Unfortunately, adequate studies to determine whether the overall effect of bracing on bones is positive or negative are not available.

**VERTEBRAL AUGMENTATION PROCEDURES**

Vertebral fractures have several long-term sequelae, including kyphosis, a protuberant abdomen, decreased exercise tolerance, early satiety and weight loss, sleep disorders, loss of self-esteem, and depression that affect the patient's quality of life and long-term morbidity and mortality [94]. Vertebroplasty and kyphoplasty are two commonly performed procedures that address some of these issues [95]. Both these procedures involve percutaneous injection of polymethylmethacrylate (PMMA) into a fractured vertebra. In addition, kyphoplasty involves a percutaneously delivered balloon tamp that is inflated in the vertebral body, which may restore vertebral body height and reduce the kyphotic angulation of the compression fracture before PMMA injection [95]. Recently some of the manufacturers of vertebroplasty products also have developed a balloon system similar to kyphoplasty [96,97].

The mechanism of action for pain relief is not completely clear, but it may involve mechanical immobilization of the fracture site and support to the innervated, painful cortex [95]. Several studies have reported up to 90% pain relief and significant improvement in quality of life with both procedures [98-102].

The immediate complications from vertebroplasty and kyphoplasty can be divided into those related to cement leakage and those related to the procedure itself [103]. Leakage of the PMMA cement is the most common complication reported with both vertebroplasty and kyphoplasty. The leakage can be epidural, paraspinal, intradiskal, foraminal, or vascular including pulmonary embolism. Although a majority of cement leakage is asymptomatic (96% in vertebroplasty and 89% in kyphoplasty), the long-term effects of these "benign" leaks are unknown. Complications of the procedure itself include infection; fractures of the transverse process, pedicle, sternum, and ribs; and respiratory distress caused by the anesthetic. Both procedures seem to increase the rates of accidental vertebral fractures [104,105]. A position statement by a combined group of radiology and neurosurgery organizations stated that because kyphoplasty is approximately 2.5 times more expensive than vertebroplasty, a substantial clinical benefit over vertebroplasty would have to be proved to justify this cost. Kyphoplasty is thus considered an alternative procedure to vertebroplasty [106].

The authors of 2 recent reports have questioned the efficacy of vertebroplasty [107,108]. In these randomized, double-blind controlled trials, the authors concluded that vertebroplasty is no better than sham therapy. However, several limitations existed in the study design, patient selection, methodology, and study end points (Table 2) [107-118]. Nonetheless, mainstream media were quick to label vertebroplasty as a useless procedure. The studies led to a wave of rebuttals [109-114] from clinicians (including some who were part of the trial [114]) who refuted the conclusions of both studies by means of letters to the editor, editorials, and commentaries in several leading medical journals. Probably one of the key reasons for such widespread disagreement with these studies is the "cognitive dissonance" between the clinically observed efficacy of vertebroplasty in providing pain relief in appropriately selected subjects and the lack of efficacy claimed by the 2 articles [109,110]. Many practitioners have not altered recommendations about these procedures on the basis of the negative articles [115,116].

Vertebroplasty might have the best outcomes if offered to patients who have an acute to subacute fracture, whose
SUMMARY AND CONCLUSIONS

It is clear that the physiatrist has a special role to play as part of the osteoporosis/fracture management team. Of all of the nonpharmacologic techniques, the greatest scientific support exists for exercise, although many of the studies have obvious shortcomings. The exercise prescription is an important part of management to prevent falls and fractures. Although WBV appears to hold promise, more studies are needed before it can be routinely prescribed. HPs are widely available, and some evidence shows that patients who wear them will have fewer fractures. Nonetheless, having patients wear HPs regularly is very challenging, often in the frailest patients who are at the highest risk of sustaining a fracture. LIPUS appears to improve fracture healing in some studies and requires further investigation. Bracing remains controversial because the improvement in mobility caused by pain relief needs to be balanced against the potential negative effects from unloading the skeleton. Finally, vertebral augmentation procedures have been used by physiatrists for pain relief after acute vertebral fracture. Results have been mixed, and the procedure remains controversial. In any event, physiatrists need to consider use of these methods, participate in research studies, and devise novel ways to improve bone health and prevent fractures.

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