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ORIGINAL ARTICLE

Critical appraisal of physical rehabilitation measures after osteoporotic vertebral fracture

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Abstract Osteoporosis is asymptomatic until fracture occurs. Fracture of the vertebral bodies can be "silent" and is diagnosed incidentally on radiographic visualization. The occurrence of spontaneous vertebral fracture in an otherwise healthy individual is considered pathognomonic of spinal osteoporosis. Osteoporotic vertebral fractures and kyphotic posture are no longer disorders about which nothing can be done. Resistive training exercises can decrease the risk of vertebral fractures. Proprioception generated within joints, ligaments, and muscles contributes to awareness of the relative orientation of functional units of the spine at rest and in motion. This is fundamental to posture, balance, and locomotion. Proprioception reeducation can be utilized for improving posture and balance. The focus of this review is rehabilitative measures for management of vertebral fractures.

Keywords Back resistive exercises · Balance · Fracture · Joint proprioception · Osteoporosis rehabilitation

Musculoskeletal challenges of aging

Bone loss and osteoporosis cause an imbalance in musculoskeletal stability. Increased bone porosity decreases the biomechanical competence of bone. Trauma to the skeletal structure can vary from gravity alone to the high impact of a moving, energized body part to the floor. The point of no return from fracture is defined by bone mass and strength.

Musculoskeletal changes related to aging are more challenging for the female skeleton. One study compared the bone ash weight of human vertebral bodies (L3) in cadavers of men and women aged 18–96 years. The bone mass in women was substantially lower than that in men of the same age [1]. Women start their life with lower bone mass and muscle strength [2].

Bone remodeling proceeds at different rates in different parts of the skeleton. Cortical (compact) bone, found primarily in the long bones of the appendicular skeleton, remodels more slowly than trabecular (cancellous) bone, found in the axial skeleton. Therefore, with sudden gonadal atrophy at menopause, women have exponential loss of axial bone mass. The result is 47% bone loss from the spine throughout a woman's life [3]. The most substantial bone loss occurs after menopause, usually at age 50–60 years. In men, the reduction in reproductive hormones is more gradual, and axial bone loss occurs at a slower rate and is about 30% throughout life. The loss of bone density in the appendicular skeleton is about 30% in women and 15% in men [4]. Therefore, in men and women, the axial skeleton is challenged more than the appendicular skeleton, but to a lesser degree in men.

Skeletal structures are physically and kinematically acted upon by muscles. Axial and appendicular muscle strength in boys and girls is about the same until age 10 years, when a disparity begins to develop [2]. Muscle strength decreases with age in men and women [5]. Sarcopenia has more effect on type II fibers ("fast twitch") than on type I fibers. This expands the type I motor neuron units at the expense of type II fibers [6]. The muscles, therefore, become smaller and weaker. The consequence of these changes is a decrease in the protective role of muscles in musculoskeletal health. This reduction becomes more challenging for women because they have lower muscle strength than men [5] (Fig. 1). In one study, back and upper and lower extremity muscle strength were measured in healthy men and women aged 21–89 years [5]. Comparison of the two sexes showed that women's muscle strength was lower than men's at all ages. Indeed, the back extensor strength of women at different decades ranged from 54% to 76% that of men.

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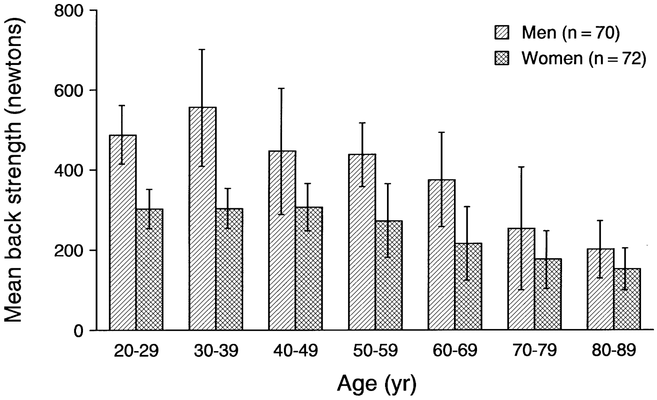

Fig. 1 Back extensor strength in men and women during the third through ninth decades of life (from Sinaki et al. [5], by permission of Lippincott Williams & Wilkins)

The discrepancy in back muscle strength between the sexes decreased with age. Across the decades, men lost 64% of back extensor strength and women lost 50% [5].

Back pain

Osteoporosis can result in two types of back pain: acute or progressive and chronic. Chronic back pain and kyphotic posture can develop insidiously as a result of vertebral microfractures. Because the ligamentous structures of the spine contain pain fibers, their persistent stretch is perceived as pain. The kyphotic or kyphoscoliotic deformity associated with osteoporosis and the resulting iliocostal friction syndrome is painful and interferes with participation in daily physical activities. Scoliosis develops in 58% of patients with idiopathic osteoporosis. Also, osteoporosis develops in 76% of persons with idiopathic kyphoscoliosis [7]. These deformities can interfere further with paraspinal muscle kinesiology and reduce muscle strength. Hyperkyphosis can decrease vital capacity [8] and interfere with participation in an exercise program. A study comparing the back extensor strength of normal women with that in women who had osteoporosis showed that strength in women with osteoporosis was substantially lower when controlled for age [9].

Performing isometric contractions of paraspinal muscles (back extensors) can decrease post-fracture pain and edema. Later, when tolerated, strengthening exercises need to be initiated. One study showed that having one vertebral fracture increases the incidence of further vertebral fractures [10]. Back strengthening exercises are helpful for decreasing the risk of further fracture of the spine [11]. Of special note, spinal extensor exercises also should be combined with exercises to reduce the increased lumbar lordosis that can occur with thoracic hyperkyphosis [12] (Fig. 2). For implementation of a posture training exercise program, isometric abdominal strengthening exercises should be included with the back strengthening program when possible [12].

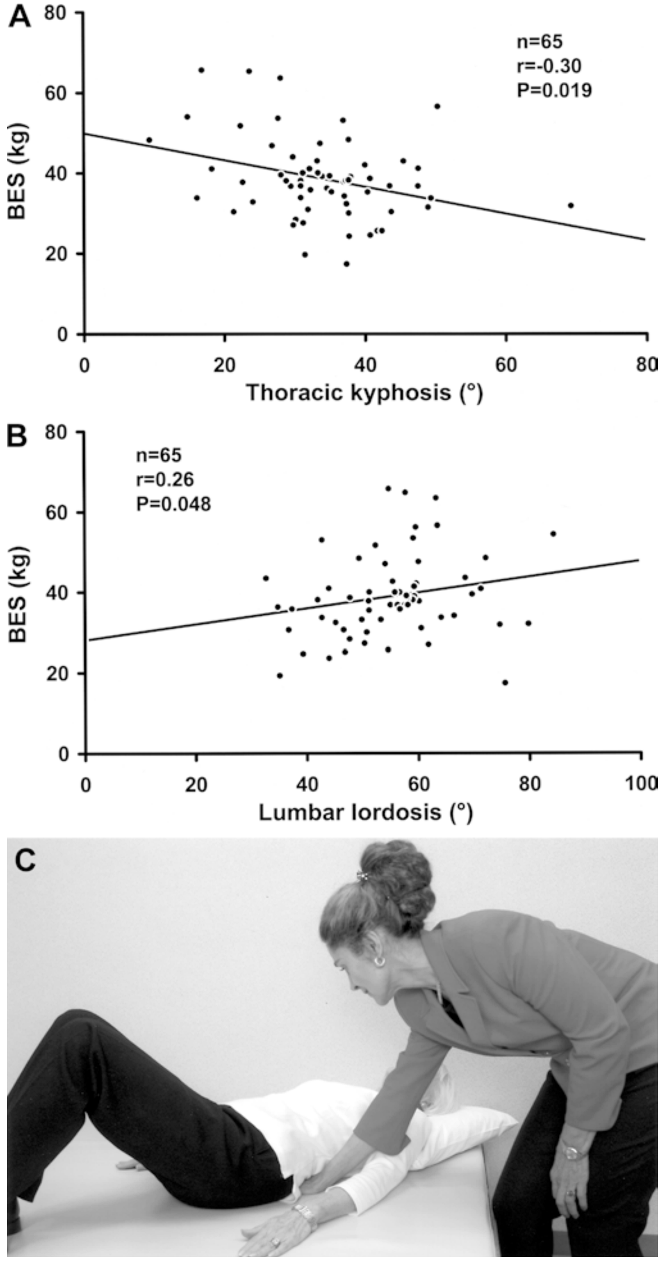

Fig. 2 **A** Back extensor strength (*BES*) and thoracic kyphosis: there was a significant negative correlation between BES and thoracic kyphosis (the stronger the back extensors, the smaller the thoracic kyphosis). **B** BES and lumbar lordosis: there was a significant positive correlation between back extensor strength and lumbar lordosis (from Sinaki et al. [12], by permission of Lippincott Williams & Wilkins). **C** Pelvic tilt exercise to improve control of quadratus lumborum and decrease lumbar lordosis

Non-pharmacotherapy and osteoporotic fractures

Musculoskeletal health depends not only on healthy bones but also on strong supportive muscles. Therefore, managing osteoporotic fractures requires pharmacotherapy for improvement of bone mass and nonpharmacotherapy (i.e. exercise) for improvement of muscle strength and posture. Proper nutrition is needed to expedite healing of fractures and early mobilization [13]. In subjects with an appropriate intake of calcium and vitamin D, protein supplements to correct inadequate protein intake improved the outcome of hip fracture and bone loss from the proximal femur [13].

The basic general principle for non-pharmacotherapy and rehabilitation after fracture is to decrease pain and facilitate mobilization as quickly as possible after the fractured area is stabilized. The main objective of physical management is to eliminate pain-induced reflex inhibition. Spinal compression fracture and pain can produce an imbalance between the use of back extensors (the major trunk supportive muscles) and flexors [14]. The pain-induced inhibition results in overuse of spinal flexors that will further contribute to hyperkyphosis. Therefore, it is necessary to relieve pain through reduction of edema in the soft tissue surrounding the fractured area. Cryotherapy has been proved beneficial in the management of post-traumatic edema [15,16] and is commonly prescribed at the acute stage of vertebral fracture. The result of vertebral wedging and compression fracture is increased thoracic hyperkyphosis. Compression fractures occur most often at the mid thoracic and upper lumbar spine, followed by the lower thoracic and lower lumbar spine, and rarely in the upper thoracic spine [17]. To decrease painful contractions of the erector spinae muscles, one needs to decrease the load over the anterior aspect of the spinal column and vertebral bodies through use of a weighted kypho-orthosis positioned below the inferior angles of the scapulae [18] (Fig. 3).

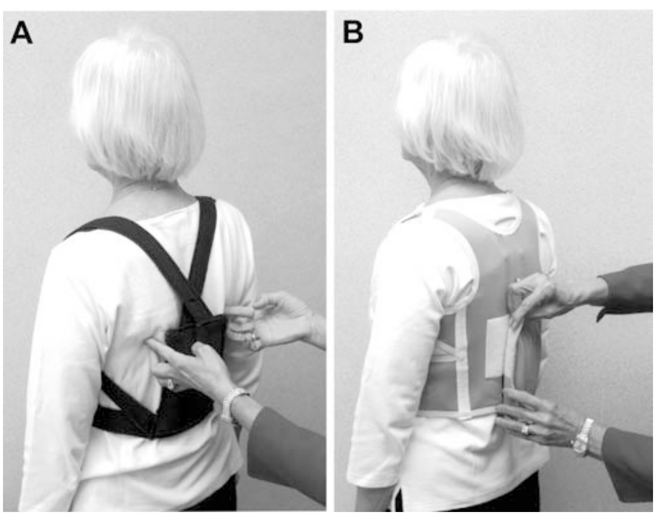

Fig. 3 Application of weighted kypho-orthosis below the inferior angles of the scapulae. **A** Universal posture training support (*PTS*). **B** PTS vest. Weights fit into a pocket on the Universal PTS, and weights are attached to the vest with fastening tape

Resistance training and fracture risk

Kyphotic posture and vertebral fracture are no longer disorders about which nothing can be done. The role of muscle strength in the maintenance of musculoskeletal health has not received adequate attention. Therapeutic exercise plays a substantial role in the management of post-fracture spinal pain [17] and in the prevention of further fracture [11]. The mechanism by which exercise decreases pain is not totally understood. In a randomized 10-year follow-up study, improved axial muscle strength in the resistance exercise group was associated with a reduction of spinal bone loss ($P=0.0004$) and incidence of vertebral fractures ($P=0.02$) [11] (Fig. 4). The long-term effect of back resistance training on the spine after its cessation was reported in a controlled, randomized, 10-year follow-up study of estrogen-deficient women [11]. The relative risk of compression fracture was 2.7 times greater in the control group than in the back exercise group. In that study, the back strength of the subjects (control and exercise groups)

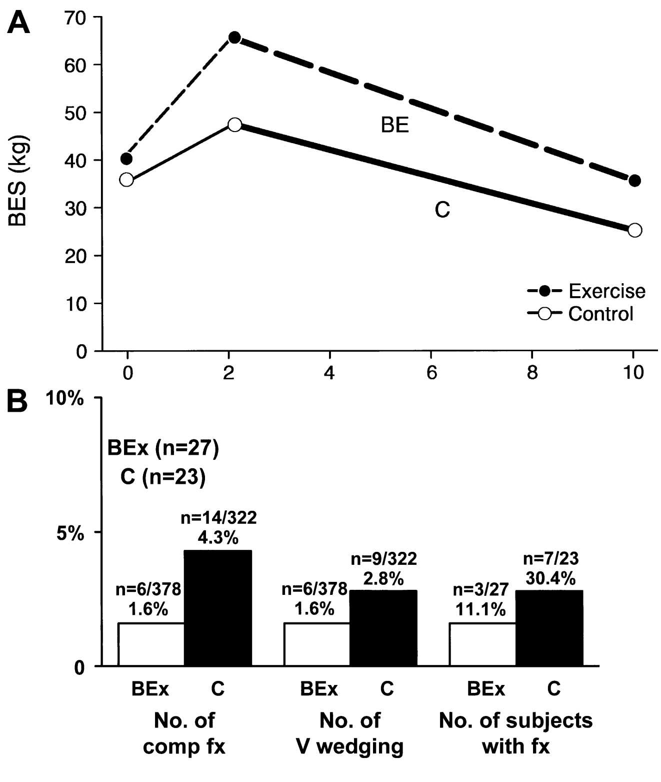

Fig. 4 **A** Back extensor strength (*BES*) in two study groups: back exercise (*BE*) and control (*C*). Subjects participated in self-selected physical activities during years 3 through 10. In both groups, BES increased at 2 years ($P=0.0001$) and decreased at 10 years ($P=0.0001$). The BES of the BE group was significantly greater than that of the C group at both 2 years ($P=0.0005$) and 10 years ($P=0.0357$). The values are mean ± SD (from Sinaki et al. [11], by permission of Elsevier Science). **B** The number of vertebral compression fractures (*Comp fx*) was 14 in 322 vertebral bodies examined (4.3%) in the *C* group and six fractures in 378 vertebral bodies examined (1.6%) in the back exercise (*BEx*) group (χ^2 test, $P=0.0290$)

Fig. 5 Model demonstrating back-strengthening exercise with a backpack containing sandbag weights (from Sinaki et al. [43], by permission of Mayo Foundation for Medical Education and Research)

was measured every 4 weeks. On the basis of their strength, participants in the exercise group were instructed to perform specific, progressive, resistive weight-lifting to strengthen their back extensor muscles with a calculated safe amount of weight (30% of their maximal weight lifted) (Fig. 5). After 2 years of progressive resistive exercises for the back extensors, the exercise group discontinued the prescribed exercises. At follow-up 8 years later, the exercise group still was significantly stronger than the control group ($P=0.03$) and had less loss of height, although this difference was statistically insignificant [11]. Suspected but not proved until now, the positive effect of resistance training on bone mineral density and reduction of risk of vertebral fracture is encouraging. An animal study showed that mechanical loading improves bone strength through reshaping the structure of bone without increasing bone mineral density [19]. Therefore, reduction of the risk of vertebral fractures in humans with resistance training (without increasing bone mineral density) also could be due to the effect on orientation of bone structure rather than on increased bone mineral density [11].

Exercise compliance

Reportedly, compliance with any exercise program is difficult to maintain [20]. In addition, the most significant gains in muscle strength are realized in the first 3 months, with fewer or slower gains after that [21]. Therefore, for maintenance of musculoskeletal health, periodic short-term courses of good compliance with intensive exercise may be more beneficial than long-term programs with poor compliance [20,22].

Spinal extension versus flexion exercises

The spine is supported by four groups of muscles: extensors, flexors, lateral flexors, and spinal rotators [23]. The massive musculotendinous bulk over the upper sacral and lower lumbar vertebrae is the origin of the erector spinae muscles. The main supportive muscles of the spine are the back extensors [14], and their role in erect posture is to resist gravity. Abdominal muscles have no spinal attachments but are important spinal flexors and also facilitate rotation of the trunk. Contraction of the spinal flexors and flexion of the spine can increase intradiskal pressure substantially [24].

The pedicle facet complex normally bears 20% of the intervertebral load; the remaining 80% is absorbed by the intervertebral disk [24]. Adjacent vertebral bodies and the intervertebral disks between them form the shock-absorbing units of the spine. Increasing age decreases the resilience of the intervertebral disks [25]. Therefore, the increased compressive forces on the spine are transferred directly to the porous vertebral bodies during flexion of the spine, whereas the posterior segment protects the neural structures and directs movements of the units in flexion and extension.

The intradiskal pressure at various positions of the spine has been measured at the L3 level [26]. The highest compressive forces on the spine are during lumbar flexion and sitting, and they decrease with standing. The lowest intradiskal pressure is in the supine position [26]. Functional spinal units permit more natural flexibility at the lumbar and, to a lesser degree, lower thoracic spine [27]. Therefore, not surprisingly, a considerable number of vertebral fractures occur at the mid thoracic spine, where flexibility is not present and gravity forces are maximal because of anatomical kyphosis and increased forces at the thoracic concavity [17] (Fig. 6). One study of comparable groups of women with osteoporosis showed that 89% of the subjects who performed spinal flexion and bending exercises increased the number of their vertebral compression fractures ($P=0.001$) [17]. Among the women who performed no exercises but mainly applied heat and massage, more compression fractures developed in 67% of the subjects ($P=0.001$). However, only 16% of the group that performed back extension exercises developed further compression fractures ($P>0.06$) [17] (Fig. 7). Therefore, the results of this and other controlled trials [11] (Fig. 4B) substantiate the importance of back extensor strengthening exercises for reducing the risk of vertebral fractures, whether for prevention or for treatment.

Clearly, persons with osteoporosis or a fragile skeleton should avoid spinal flexion exercises and loading of the spine in a flexed posture [17].

Orthotics and the osteoporotic spine

Orthotics are important in the care of the osteoporotic spine. After fracture, in the acute pain stage, supporting the spine reduces motion of the apophyseal vertebral joints as well as flexion and extension of the spine. By decreasing the patient's pain, overguarding of the spine and immobility are reduced [28]. To avoid atrophy of supported back muscles, the use of spinal supports needs to be discontinued as soon as pain subsides [29].

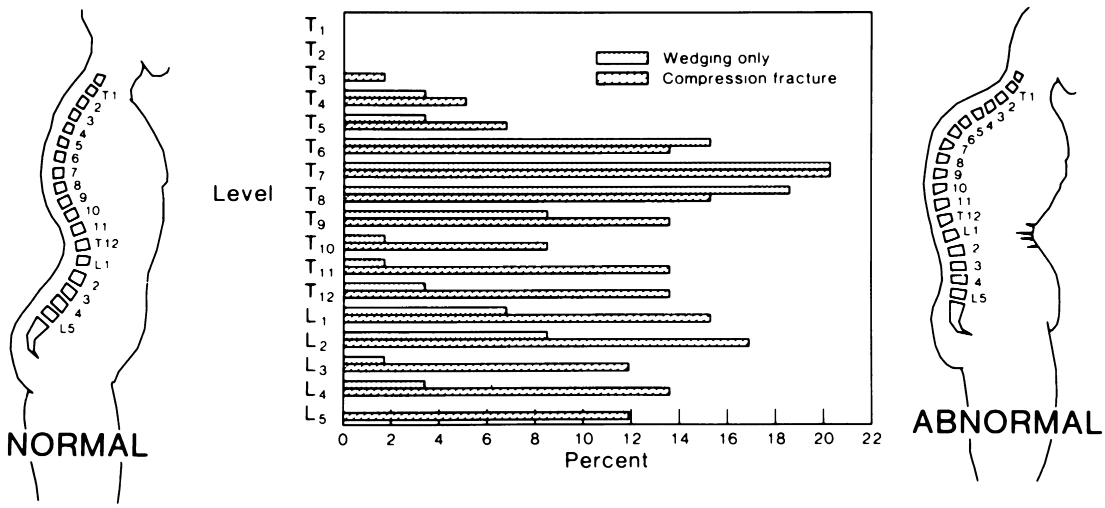

Fig. 6 Osteoporosis-related incidence of wedging and compression fractures at various levels of the spine on radiographic evaluation (from Sinaki and Mikkelsen [17], by permission of WB Saunders)

At the chronic back pain stage, posture-training spinal orthotics can be used to decrease pain related to kyphotic deformity and secondary pain due to overstretched ligamentous structures of the spine [18]. This was demonstrated first through an open study [18] and then in a randomized trial [30].

Post-fracture proprioception reeducation

Receptors in muscles, tendons, joints, ligaments, and skin all play a role in proprioceptive input [31]. Therefore, joint position sense is fundamental to posture, balance, and locomotion. Post-fracture pain-induced reflex inhibition and vertebral deformity can interfere with the kinesiology of the spine and proper recruitment of paraspinal muscles for support of the spine. Therefore, muscle reeducation through biofeedback techniques is important to improve synchronized muscle contraction during movement of functional units of the spine. In a controlled, randomized trial using electrical stimulation to the lumbar paraspinal muscles, back muscle strength improved extensively at 3 months ($P < 0.03$) [32]. Another study showed a 55.5% improvement in the computerized balance test score in subjects who used a proprioceptive dynamic posture (PDP) training program at the T10 level of the spine and continuation of deterioration of balance in those who performed back exercises only [33] (Fig. 8). In yet another randomized controlled study of the effect of PDP and bracing on back muscles, improvement of back extensor strength was compared in three groups of women with osteoporosis who performed back extension exercises [30]. The group that used PDP and a Posture Training Support and performed back extension exercises increased their back strength considerably

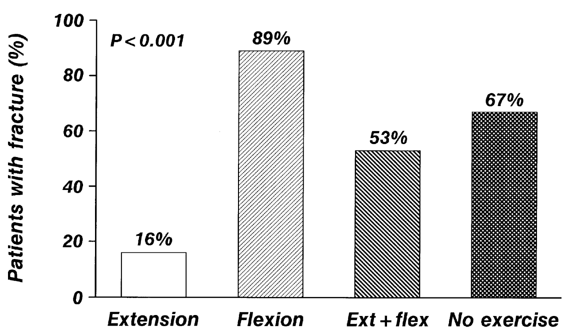

Fig. 7 Percentage of patients with compression fracture in extension exercise, flexion exercise, extension and flexion (*Ext+flex*) exercise, and no exercise groups (from Sinaki [44], by permission of the publisher)

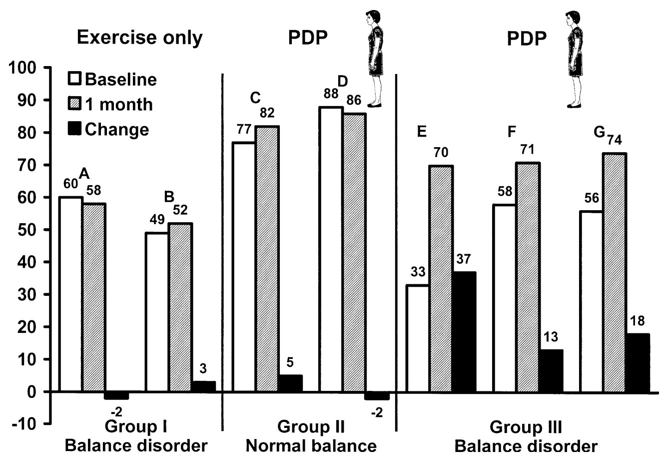

Fig. 8 Changes in balance, tested with computerized dynamic posturography (*CDP*), from baseline to 1 month follow-up in seven subjects (**A–G**). Group 1 (with abnormal baseline CDP) received exercise therapy only; group 2 (with normal baseline CDP) received exercise plus proprioceptive dynamic posture (PDP) training; group 3 (with abnormal baseline CDP) received exercise plus PDP. The maximum improvement in balance occurred in group 3, which had abnormal baseline CDP and received PDP training (from Sinaki and Lynn [33], by permission of Lippincott Williams & Wilkins)

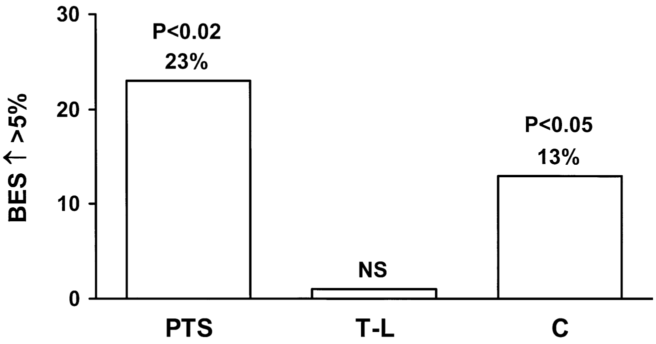

Fig. 9 Results of orthotics on back extensor strength (BES) (data from Kaplan et al. [30]). *C* control group, performed exercise only; *PTS* group, used Posture Training Support, proprioceptive dynamic posture training, and exercise; *T-L* group, used thoracolumbar brace and exercise

compared with the control group ($P < 0.02$) (Fig. 9). The group that used thoracolumbar rigid bracing did not improve their back strength despite the back exercises. The control group, who performed the exercises only, without bracing, also improved their back strength but not as much (Fig. 9). The same study showed poor compliance with use of the thoracolumbar rigid orthoses [30]. Thus, the role of thoracolumbar rigid bracing in the prevention of spinal fractures is questionable.

Kyphosis contributes to the compressive forces over the anterior half of vertebral bodies. Microfractures may develop more easily, with an increment in thoracic kyphosis. PDP muscle reeducation can decrease thoracic kyphosis and reduce pain [34,35,36].

Reduction of the risk of falls

Even in healthy persons, predisposition to falls increases with age-related proprioceptive changes [37]. Postural stability and balance performance decrease with age. In 1990, Peterka and Black [38,39] reported on balance performance and the incidence of loss of balance in 214 healthy subjects aged 7–81 years. The majority of falls during computerized balance testing occurred in subjects older than 50 years. Further, the amount of body sway increased with age. Therefore, measures that can decrease body sway can decrease the risk of falls [33]. In a study of PDP, balance improved with enhancement of postural proprioception and with reduced hip strategy. In normal balance, ankle strategies are recruited rather than hip strategies [35]. Strengthening of the lower extremity muscles reduces the risk of falls [40]. One study showed that kyphotic posture in persons with osteoporosis contributed to the risk of falls [35]. Another study [33] showed that reducing kyphosis through proprioceptive training can reduce the risk of falls. Preliminary results of an ongoing study incorporating the use of a weighted kypho-orthosis and PDP for decreasing the risk of falls have been promising ($P = 0.002$) [41]. Gait aids also may decrease the risk of falls if the patient is receptive to using one and is diligent in its use [42].

Conclusion

Reduction of bone mass and osteoporotic fractures creates specific challenges that cannot be met with pharmacotherapy alone. Physical rehabilitative measures play a key role after fracture and beyond for preventing further fracture. Muscle re-education, resistance exercises for strengthening, and reduction of kyphosis are key elements for reducing the risk of falls and further fracture. Global programs for prevention and management of osteoporotic fractures should include physical rehabilitation measures. In the long term, critical evaluation of rehabilitation measures can be very economical if the unnecessary use of rigid bracing, gait aids, and wheelchairs is reduced significantly. In addition, reducing immobility can save lives because mobility can decrease further bone loss and prevent deep venous thrombosis, pulmonary infection, or even death. There is a dearth of controlled trials in this area, perhaps because of the lack of funding for non-pharmacologic research. Some of the studies referenced in this review included small numbers of subjects, but it is hoped that they will pique interest for larger studies. Further studies investigating post-fracture muscle strengthening techniques, reduction of kyphosis, and prevention of falls will help support our conviction that non-pharmacologic rehabilitative management of osteoporosis, when properly used, is beneficial and cost-effective. Physical rehabilitative measures play a key role after fracture and beyond for preventing further fracture. Muscle reeducation, resistance exercises for strengthening, and reduction of kyphosis are key elements for reducing the risk of falls and further fracture.

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