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Physical Exercise for Prevention of Falls and Fractures

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1. Introduction

Osteoporosis is a metabolic bone disease that specially affects postmenopausal women resulting in devastating effects associated to the high social-economic impact in the population in general. The World Health Organization defines osteoporosis as a skeletal disorder characterized by a reduction in bone mass with alterations in the micro-architecture of the bone tissue leading to a decrease in bone resistance and increased susceptibility to fractures (World Health Organization, 1994; Bennell et al., 2000; Gali, 2001; Szejnfeld et al., 2007).

Bone is a highly metabolic active tissue that maintains its remodeling throughout life (Hunter & Sambrook, 2000). On the other side, bone mineral density is a result of a dynamic process of bone formation and resorption called remodeling. Resorption causes the tissue deterioration, while its deposition is responsible for the reconstruction and strengthening of the deteriorated tissue. This process occurs through life in cycles of four to six months (Bemben et al., 2000).

The bone wear out in daily life demands a process of permanent remodeling. This remodeling process renews in a year about 10% of the skeleton, that is, all bone tissue is remade every 10 years (Manolagas, 2000).

The global rate of bone resorption is regulated by the osteoclastic differentiation through the regulation of fundamental functional proteins, which specific role is to control its migration and resorption (Bruzzaniti & Baron, 2006). Osteoblasts are the cells responsible for the bone formation through the synthesis and mineralization of the skeleton and formation of osteoids (Bodine & Komm, 2006). Because the osteoids are not able to reproduce when they are damaged they go through a process of apoptosis, releasing osteoclast-forming inductors which will phagocyte them. This is the first stage for its replacement that will be performed by the osteoblasts (Manolagas, 2000).

In a regular remodeling process, there is a balance between the enzymatic production of osteoclasts and the production of a primary matrix of collagen and fixation of calcium promoted by the osteoblasts (Position Statement, 2002).

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Human beings reach their bone mass peak around age 30 years being strongly affected by genetic, representing 60-80% of the bone mass peak showed by an individual (Ramalho & Castro, 1999).

In the adult, 90% of bone mass is resting, while 10% is in constant activity to revitalize the bone tissue. Neoformation occurs only after the resorption of a damaged bone. In a year, 25% of the trabecular bone and 1% of cortical bone are remodeled by a still unknown mechanism. During growth, the balance of this renewal is positive. In the adulthood, it is even and after age 40 it starts being negative. During the age where this balance is negative, the portion destroyed is not completely remodeled and around 1% of the bone mass is lost annually (Carvalho, 2006).

The decrease in bone mineral density (BMD) with age is considered as a physiological osteopeny, being a universal phenomenon that affects all races and cultures; non-pathological by itself in most of the individuals, but it is the background to development of osteoporosis and consequently, a higher risk of fractures (Ramalho & Castro, 1999). The sequence of this negative renewal throughout the years is responsible for the primary osteoporosis (Carvalho, 2006).

During the age-related bone loss, there is an unbalance in bone remodeling, with an increase of bone resorption compared to formation. In the stage of accelerated postmenopausal bone loss, there is a high rate of bone remodeling, with an increase in the number of osteoclasts that forms a very deep resorption cavity leading to a trabecular perforation. In the slow process of bone loss, osteoclasts build a bone resorption cavity with a normal depth, however the osteoclasts fail in replacing the new bone in a proper way (Yoshinari & Bonfá, 2000).

The incidence of osteoporotic fractures (Figure 1) is strictly related to the individual bone mass that depends on the speed of loss throughout life as well as the amount of bone tissue in the end of puberty and beginning of adulthood. The great variation in bone mass peak is explained not only by hereditary factors but also by gender, race, eating habits, several hormone influence, body composition of lean mass and body fat, intercurrent diseases, chronic use of medications and physical activity (Brandão & Vieira, 1999).

Like any other chronic disease, the etiology of osteoporosis is multifactorial. Genetic factors contribute approximately with 46% to 62% of bone mineral density (BMD) whereas other causes include lifestyle, diet and physical exercise (Neto et al., 2002).

Osteoporosis is considered a "silent disease" until a fracture occurs. Approximately 1.5 million fractures per year are attributable to this disease. Only in the USA, these fractures result in 500.000 hospitalizations, 800.000 emergency room visits, 2.6 million physician visits. The treatment cost is high. In 2002, 12 billion dollars to 18 billion dollars were spent (Gass & Huges, 2006). In 1998, cost management of osteoporosis fractures in the UK recorded 942 million pounds per year (Szejnfeld et al., 2007). Because it is considered a "silent" disease, it may progress for decades before being diagnosed. *Osteoporosis* has become one of the major public health problems. Nowadays, the impact of osteoporosis is compared to the impact caused by most important health problems, such as cardiovascular diseases and cancer (Froes et al., 2002).

It exposes the fallers to a high risk of fractures (Johnell et al., 2005; Siris et al., 2006). The first hip fracture is associated to 2.5-fold increased risk of subsequent fracture (Cólón-Emeric et al., 2003) with a high level of morbidity and mortality (Cathleen et al., 2006).

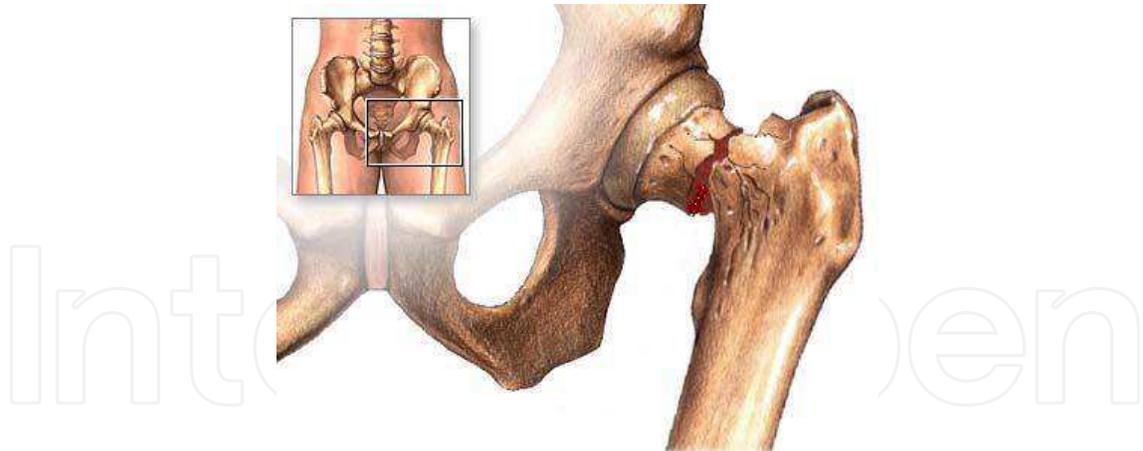


Fig. 1. A femoral neck fracture of the hip.

It is believed that about 25% of menopausal women in the USA will exhibit some kind of fracture as a consequence of osteoporosis. The most severe fractures are the fractures of femur and they are associated with higher medical expenses than all other osteoporotic fractures together (Moreira & Xaxier, 2001). The incidence of these fractures has doubled in the last 25 years and it is estimated that six million people in the world will suffer fracture of the proximal femur in 2050. Fractures resulted from the decrease of bone mineral loss are considered an orthopedic epidemic leading to an increase in costs for several countries and consequently representing a big social and economic problem (Ramalho et al., 2001).

There have been a significant number of evidences showing that the decrease in bone quality, from generation to generation, is caused by a change in life style, having as a main determinant the lack of physical activity. This evidence varies with the biology of the basic bone. However, epidemiological studies indicate that physical activity is the most important factor to maintain bone mass and prevent fractures (Mosekilde, 1995).

Almost all hip fractures (more than 90%) occur as a result of a fall and these fractures are related not only to the decreased bone mass, but also to other factors such as reduction of balance, muscle strength and power in the lower extremities (American College of Sports Medicine [ACSM], 1995; Parkkari et al. 1999). Therefore, aging and alterations in balance and muscle strength, as well as sensorial changes, predispose patients with osteoporosis to a higher risk of having fractures due to falls.

2. Physiology of aging and falls

The aging process is associated to several anatomic and physiological changes which are directly related to musculoskeletal frailty and falls (Walsh et al., 2006).

The visual system with aging tends to decrease the visual acuity and visual field, also decreasing the speed in adjusting to dark and increase in the *threshold for luminosity* (Sloane et al., 1989).

When the somatosensorial system gets old, it show a loss of proprioceptive fibers related to *kinesthetic* sensitivity. Histological studies have shown the decrease in the number of Pacini, Merkel and Meissner corpuscles in the (Sloane et al., 1989).

The main structural and electrophysiological changes in the vestibular system due to aging are: after the age of 40 years, microscopic synaptic changes in the vestibular nerve, increase in the degeneration of the vestibular receptors mainly in the ampullary crest of semicircular

canals and saccule at the age of 50 years, preceding the decrease in the proportion of cells in the Scarpa ganglion. After the age of 60, there is an increase in friction among the fibers of the vestibular nerve, selective loss of density in the myelin fibers leading to a decrease in conduction velocity of the electrical stimuli in the vestibular nerve, decrease of the nystagmic response to caloric and rotational tests in elderly people, decrease in the optokinetic nystagmus amplitude and pursue eye movements, mainly for the visual stimulus with high speed (Vicini et al., 1989).

Qualitative and quantitative changes in the ciliated cells are observed as well cystic degenerations, fusion of cilia and lipofuscin inclusion in the cell (Isuji et al., 2000).

The loss of ciliated cells is relevant and in general occurs in five sensorial structures of the vestibular system (three semicircular canals, saccule and utricle) in elderly patients, being greater in the crista of semicircular canals than at the saccular and utricular maculae (Isuji et al., 2000).

In the elderly, the vestibulo-ocular reflex (VOR) shows a bigger capacity of compensation than the vestibular-spinal reflex (VSR) aggravating the difficult in maintaining the stability in posture stability (Enrietto et al., 1999; Norré et al., 1987). Another factor that has an influence on the postural instability in the elderly is the alteration in the neuromuscular system.

Studies have shown that the muscle strength reaches its peak around the age of 30 years and it is satisfactory preserved up to the age of 50 years (Deschenes, 2004). However, a decrease in strength is observed around the age of 50 and 60 years, with a faster decrease after the age of 60 years (Krueger et al., 2001). The muscle mass decrease around 50% between 20 and 90 years of age and the number of fibers in the elderly is approximately 20% smaller than in the adults (Rossi & Sadler, 2002).

When measured after the 50s, the progression rate related to a reduction in strength is around 8 to 15% by decade and men, as well as women, show the same pattern of strength decrease during aging (Deschenes, 2004; Krueger et al., 2001). However, longitudinal investigations have shown a greater increase in the strength reduction in seniors than the results found in transversal studies (Deschenes, 2004).

Additional complications in muscle function associated to severe or chronic diseases, hospitalizations after trauma or surgery and lack of activity might accelerate the muscular strength decrease (Krueger et al., 2001). Age-associated decrease of muscle strength mainly results in a substantial reduction in muscle mass that follows the aging process, generating a great loss of muscle mass and an increase in the subcutaneous and intramuscular fat, denominated "sarcopenia" (Wilmore & Costill, 1999; Deschenes, 2004; Hunter et al., 2004; Krueger et al., 2001).

According to Deschenes, 2004, the decrease in the number of muscle fibers is the main cause of sarcopenia, although fiber atrophy is also involved.

A decline in strength of around 30% is observed in people with ages ranging from 50 to 70 years. These changes in the muscle structure are more common in women than in men, in the lower limbs than in the upper limbs and most of this decrease is caused by a selective atrophy in type IIB muscle fibers (American College of Sports Medicine, 1998).

However, it is believed that the aging process is responsible for the loss of α motoneurons; therefore, elderly individuals would show smaller amounts of motor units. This is explained by the degeneration of neural elements, re-organization of the other components, variation in the ratio of different types of motor units and alterations in the propriety of each motor unit.

Other physiological factors also contribute for the development of sarcopenia in advanced age, such as the decreased production of anabolic hormones, which jeopardizes the musculoskeletal capacity to incorporate aminoacids and to perform the protein synthesis. An increase in the release of catabolic agents also increases the muscle wear in seniors causing a decreased supply of glycolytic enzymes and smaller supply of ATP (Deschenes et al., 2004). Studies have shown that the muscle mass starts to decrease in approximately 1% a year after the fourth decade of life. Most of the times, sarcopenia is marked by the stability of weight, due to the changes related to age in the body composition. However, several groups have reported the prevalence of sarcopenia, but these findings need to be further researched since they use different techniques to measure the lean mass and also use populations of different references. The prevalence of osteopenia and osteoporosis were estimated as 42% and 17%, respectively in women over 50 years old, where caucasian women showed the greatest number of cases of low bone density. Since the proportion of elderly older than 65 years in the population might increase, the incidence of sarcopenia and osteopenia might also increase. In women, menopause has been associated to a reduction in lean mass (LM) and bone mineral density (BMD). Several researches have demonstrated a positive relationship between LM and BMD and females with osteoporosis have been shown to have a significantly lower appendicular skeletal muscle mass compared to control groups. Based on the theory that the muscle mass is an indicator of BMD, one might speculate that sarcopenia is a risk factor for the development of osteopenia and that it is more prevalent in osteopenic individuals (Walsh et al., 2006).

Studies conducted by Walsh et al., 2006, revealed that 12.5% of postmenopausal women were osteopenic and that 25% of those postmenopausal osteopenic women and 50% of postmenopausal women with osteoporosis have sarcopenia. Therefore, they might present a higher risk of fractures compared to osteopenic women and osteoporotic women with a relatively normal skeletal muscle index.

Possible neural mechanisms that evidence this decrease in power associated to aging include the undefined changes in the CNS, a delay in the conduction velocity of motor nerve fibers and a delayed transmission in the neuromuscular junction or all three (Krueger et al., 2001). Similarly, a decrease in the number or the relative cross-sectional area of type II fibers, alterations in the sarcoplasmic reticulum and metabolism of calcium within the fibers, changes in the composition of isoforms of myosin in different fibers, functional and enzymatic properties of the myosin, an increase in the non contractile tissue, generating a greater resistance or combination of factors, might be responsible for the decreased power in the elderly (Hunter et al., 2004; Krueger et al., 2001).

The reduced capillary density and blood flow, impairment of glucose transport and lower mitochondrial density, decreased activity of oxidative enzymes and reduced rate of phosphocreatinine repletion contribute to the decrease in muscle endurance verified in people with advanced age (Krueger et al., 2001)

The loss of power might cause more damage to the elderly than the loss of maximum muscle strength since the development of explosive force is an important mechanism to prevent falls and to perform heavy duties such as velocity in rising from a chair and walking (Krueger et al., 2001; Hunter et al., 2004).

A fall can be defined as a sudden, unintentional change in position causing an individual to land at a lower level in relation to his initial position (Feder et al., 2000).

Almost all hip fractures occur as a result of a fall. These fractures are related not only to a decreased bone mass but also to factors such as a reduction in balance, strength and muscle

power in the lower extremities (American College of Sports Medicine, 1995; Nyberg et al., 1996).

The pathogenesis of fall is multifactorial (Nevitt et al., 1989; Tinetti et al., 1989). According to the Brazilian Society of Geriatric and Gerontology, 2008, the causes for falling might be divided in intrinsic and extrinsic and they are the following:

2.1 Intrinsic risk factors

- Previous history of falls – One or more falls in the previous year increase the risk of new falls in the subsequent year;
- Age – The prevalence of falls increases with age, however a review has shown that from 11 studies, only four found a positive association between aging and future falls;
- Females – In older women, the rate of women who fall is greater than in men and shows a greatest risk of fractures;
- Medications – Medications such as psychotropic drugs, cardiac medications like diuretics, antiarrhythmic, vasodilators and cardiac glycoside and polipharmacy (simultaneous use of four or more medications) are predisposing factors;
- Clinical condition – Diseases such as systemic arterial hypertension, diabetes mellitus and neurological or osteoarticular diseases affecting muscle strength, balance and gait are common risk factors. Orthostatic hypotension might be systematically researched due to its high prevalence. Severe diseases or unbalanced chronic conditions that affect the brain perfusion might also trigger a fall;
- Gait and balance disorders – They might be caused by aging itself, predisposing to falls when there is a decrease in force and endurance below the minimum threshold to perform independent daily life activities;
- Lack of physical exercise – The lack of physical exercise might cause an important musculoskeletal disorder;
- Psychological state – The fear of falling again after a fall is correlated to the worse performance of gait and new episodes of fall, which might restrict physical and social activities. Depression is also correlated to falls;
- Nutritional deficiency – It is related to the gait disorder, loss of muscle strength and osteoporosis;
- Cognitive impairment – Even a small deficit might increase the risk of fall;
- Visual impairment – Changes in acuity and visual field, as well as cataracts, glaucoma and macular degeneration are correlated to the increased risk of fall;
- Orthopedic disease – Diseases such as cervical spondilosis that might provoke dizziness, unbalance and feet problems, such as callus, deformities, ulcers and pain when walking also contribute to the genesis of fall;
- Functional state – the risk of falling is progressively increased according to the individual degree of dependence;

2.2 Extrinsic risk factors

The participation of environmental risk factors might reach, according to studies, up to 50% of the falls in elderly that live in the community. These factors include poor lighting, slippery surfaces, loose or folded rugs, high or narrow stairs, obstacles in the way (low

furniture, small objects, wires), lack of rails in halls and bathrooms, extremely low or high shelves, inadequate shoes and clothes, poorly maintained streets with holes or irregularities and inappropriate orthosis.

3. Exercise prescription

Intensity, duration, frequency and progression of the training are arguable, therefore future studies with better designs are required to evaluate these variables. Below are the exercise prescriptions for the elderly based on some consensus found in the literature:

3.1 Pre-participation

In general, the counter-indications are similar to the ones for a young adult. However, the need of a stress ECG is contradictory and it should be considered for patients with cardiac risk factors.

3.2 How to start

The exercises might have as a purpose to improve the functional limitations that seniors might have (pain, reduced movement range or muscle weakness). As soon as the limitations are improved, a program of general conditioning should be implemented to improve health and functional capacity of the elderly.

Training sessions should include three stages: warm-up, which involves low impact exercises to gain joint range of motion, training period (the effort itself), that involves muscle strengthening and/or aerobic exercises and the final stage that consists of stretching (cool down).

3.3 Stretching

Stretching should be performed during the warm up and in the last phase. A great joint range of motion (ROM) increases the muscle, reduces the risk of lesion and increases the cartilage nutrition. Painful joints should not be stretched excessively to a point that will result in more pain; all movements should be made in order to get the maximum pain-free ROM. The use of heat before stretching reduces pain and increases the range. At least three sessions of stretching might be performed a week. In the beginning, three to five repetitions and a gradual increase up to 10 repetitions is the ideal. The muscle should be stretched during 10 to 30 seconds.

3.4 Muscle strengthening

Muscle strengthening should be acquired with weights or elastic bands which will give endurance to the movement. The training protocols should include the following principles:

- muscle contraction exercises should be made in a moderate speed;
- exercises should be chosen according to joint stability and degree of pain and edema;
- muscles should not be exercised to fatigue;
- exercise endurance should be submaximal;
- inflamed articular joints should be strengthen with isometric exercises and at first it should include few repetitions;
- pain or edema in a joint after an hour of exercise indicates excessive activity.

- Isometric exercises are indicated for unstable or swollen joints. On the other hand, isometric contractions result in a low articular pressure and are well tolerated by older patients. It should start with contractions with an intensity of approximately 30% of maximal strength, slowly increasing to 80%. The contraction should not be kept for more than 6-10 seconds and the repetitions should be increased from 8 to 10, if tolerated by the patient. It should be performed twice a day during the inflammatory period and after the inflammation is over, it should be increased from 5 to 10 times a day.
- Isotonic exercises should include from 8 to 10 exercises involving the major muscle groups (four exercises for the upper limbs and from four to six for the lower limbs). At first, patients should use weights with 40% of the individual's maximal load, increasing up to 80%. Generally, a series of four to six repetitions should be made, avoiding the muscle fatigue. At first, the frequency should be at most twice a week but in case of individuals with advanced age or significant fragility the exercises should be made only once a week. Between the sessions, there might be at least one full day of rest.

4. Physical exercise to prevent falls

Prevention in individuals older than 60 years has an important role in avoiding adverse consequences resulting from falls (Weatherall, 2004).

The work to prevent fractures related to osteoporosis should focus the prevention or increase of material and structural properties of the bone, the prevention of falls and improvement of total mass of lean tissue (American College of Sports Medicine, 1995).

The American College of Sports Medicine recommends that:

1. physical activity of transporting weight is essential to the normal development and maintenance of a health skeleton. Activities that focus the increase of muscle strength might also be beneficial, particularly for bones that do not support weight;
2. a sedentary woman might progressively increase her bone mass by becoming active, but the primary benefit of increasing the activity is to prevent a future bone reduction that resulting from the lack of activity;
3. exercise should not be recommended as a replacement to medications treatment;
4. the optimal program for an older woman might include activities that improve the strength, flexibility and coordination which might indirectly, but effectively decrease the incidence of osteoporotic fractures by reducing the probability of falls. Therefore, the treatment of osteoporosis should aim the prevention of falls and fractures and preservation or improvement of bone mineral density.

4.1 Exercises for postural control

Postural control is a result of the combination of several types of sensorial information, such as visual, vestibular and somatosensorial information, and passive and active properties of the nervous system and skeletomuscle system that composes the human postural control system (Figure 2), (Shumway-Cook et al., 2000).

The postural control system use three functions that are required to maintain balance: support, stabilization and balance. The body should contract the adequate muscles to sustain the body against gravity; the articular segments should be stabilized and the body should be stabilized in the body's support base (Rothwell, 1994).

Currently, proprioception is defined as a set of afferent information provided by joints, muscles, tendons and other tissues that reaches the Central Nervous System (CNS) where it

is processed, having an influence on reflex responses and voluntary motor control. Proprioception contributes to postural control, joint stability and several conscious sensations (Lephart & Fu, 2000).

It is extremely important to understand that proprioception is only limited to the acquisition of the mechanical stimulus and its transduction in neural stimuli, not having any influence on the CNS processing and its motor response (Lephart & Fu, 2000).

Proprioception is part of a system denominated somatosensorial system. This includes all mechanical information provided by the mechanoreceptors. The feeling of pain is provided by the nociceptors and the thermal information provided by thermoreceptors (Guyton & Hall, 2006).

All proprioceptive information are originated at the muscular and tendon receptors called muscular fusion and Golgi tendon organ and receptors located in ligaments, articular capsule, meniscus and cutaneous tissues (Guyton & Hall, 2006).

Four elements should be focused to reestablish the sensorimotor deficits: proprioception, stabilization, reactive neuromuscular control and functional motor patterns (Lephart & Henry, 1995).

The proprioceptive mechanism comprises both conscious and unconscious pathways. Therefore, the prescribed exercises need to include conscious exercises to stimulate the cognition as well as sudden and unexpected alterations of joint position that initiate reflex muscle contraction. These exercises should involve balance in an unstable surface while the individual perform functional activities. The purpose of the dynamic stabilization training is to improve the co-activation between the antagonist muscles (Hurd et al., 2006)

Exercises to stimulate proprioception and dynamic stabilization should be performed in closed-chain activities and with small movements, since the compression stimulates the articular receptors and the changes in the curve length-tension stimulate the muscle receptors. Limbs repositioning exercises should also be performed to stimulate the sense of joint position and neuromuscular control (Lephart & Henry, 1995).

The improvement of dynamic stiffness is another important aspect. It is suggested that muscle receptors increase its sensitivity through the increase of dynamic stiffness (Adler et al., 2008).

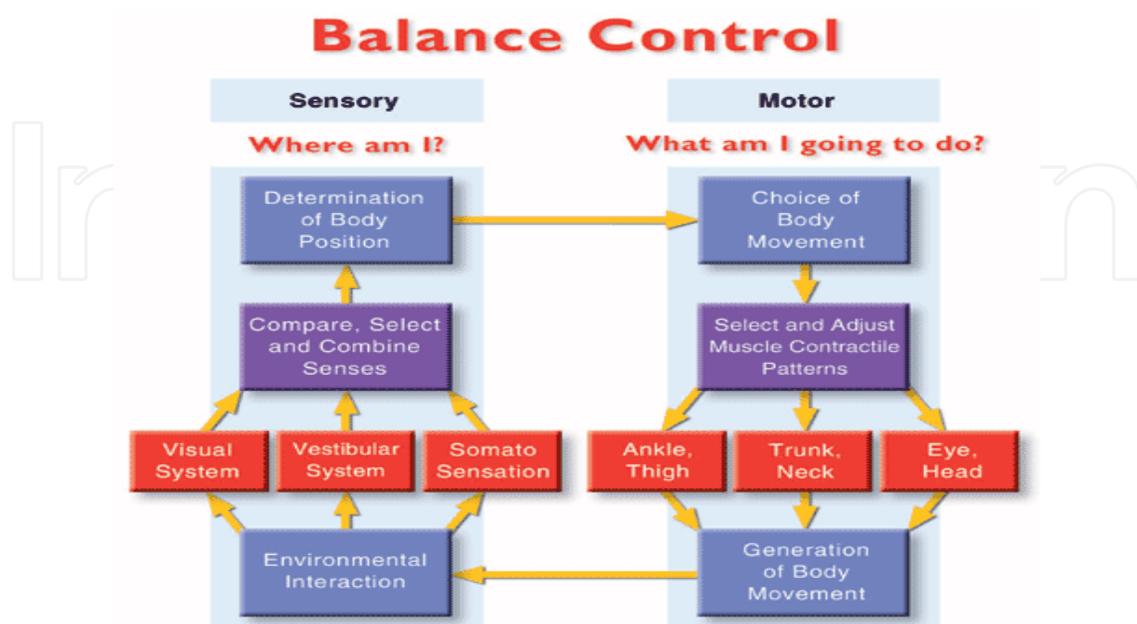


Fig. 2. Balance control: Sensory and motor system. Credit: <http://resourcesonbalance.com>

Exercises that involve eccentric training, like going down the stairs and landing after jumps, are the most efficient to increase anticipatory and reactive muscular stiffness (Bastian et al., 2006).

The reactive neuromuscular control is reached through exercises that create unexpected situations, such as perturbations in unstable surfaces in unipodal support and during gait. Apparently, this kind of training improves the preparatory and reactive muscle activation (Swanik et al., 2002).

The training protocol might include:

1. 5 - 10 minutes of warm-up, with stretching movements for upper and lower limbs, 03 repetitions for each movement being kept for 30 seconds, with 30-second intervals among the series. After stretching, movements of fast gait as previous warm-up were performed and in the end of the session, slow gait movements and stretching.
2. Proprioceptive exercises followed an evolution sequence based on the use of stable surfaces to unstable, walking straight forward progressing to changes in direction, from gait with no obstacles to gait with obstacles, alteration in the support base (from open to closed), exercises with eyes open to closed eyes, always respecting the functional capacity of each patient and progressively increasing the difficulty of each exercise. To aid the training, cones, balance boards, sticks, mats and trampolines were used. According to the patient's evolution, the exercises were combined creating the circuits (Figure 3).

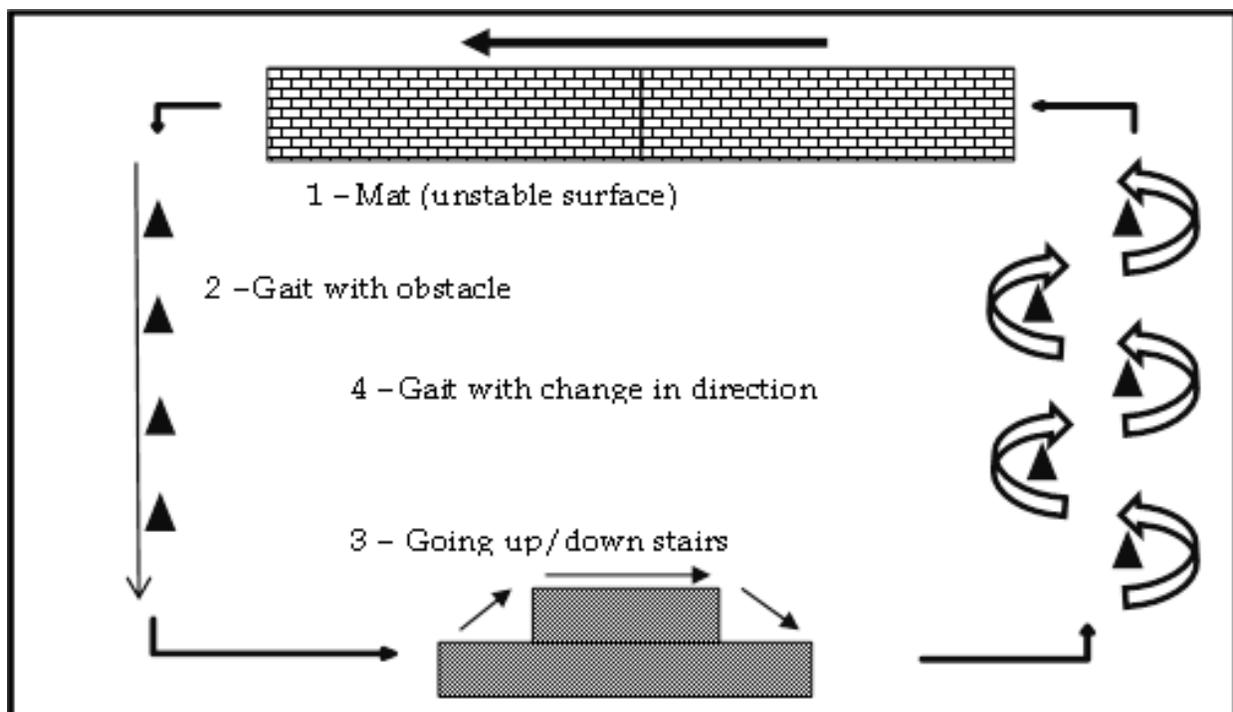


Fig. 3. Example of a circuit training

Examples of exercises: ten repetitions with one-minute intervals for antero-posterior and latero-lateral gait; gait with obstacles (20 cm high); gait over mattress; going up and down the stairs; change in direction according to the sound stimulus; balance exercises lasting 30 seconds and with one-minute interval for unipodal and bipodal support on the floor

with eyes open and/or closed; change in floor for a more unstable surface such as a trampoline and balance board; exercises with dissociation of waist and use of a stick (Table 1).

Options of Exercises	Evolution of Exercises	Time or # of repetitions
Balance exercises (balance board, mini-trampoline, Dyna disc)	Eyes open or closed / stable or unstable	10 rep / 30s
Stability exercises	Unipodal or bipodal support / open or close base	10 rep / 30s
Anteroposterior and latero-lateral gait	With or without obstacle and Variation in speed	10 rep (3 m)
Mat exercises	Go up/down: 1 to 3 mats	10 rep / 3 series
Exercises on the stairs	Variation in speed	10 rep / 3 series
Exercises with sticks	With or without arm movements	10 rep / 3 series

Table 1. Examples of exercises

Evidences have shown that specific exercises might reduce the risk factors for falls and number of falls in older people (Lord & Clark, 1996; Robertson et al., 2001-1, 2001-2; Hartard et al., 1996).

In 2006, Carvalho stated that the main goal of the osteoporosis treatment is to prevent fractures and as 90% of the fractures resulted from falls, the fundamental part of fracture treatment is to prevent them. This prevention represents a great area of interest in researches on older people's health (Weatherall, 2004).

Because of the strong interaction between osteoporosis and falls, the selection of participants in protocols for the prevention of fractures should be based on factors related to bones and falls (Pfeifer et al., 2004).

The German Society of Sport Medicine and the American College of Sport Medicine also recommend that the ideal program for women with osteoporosis should include activities that improve strength, flexibility and coordination that might indirectly and more effectively decrease the incidence of osteoporotic fractures by the reduction in the probability of falls (Lange et al., 2005).

Data combined from three studies conducted by Gillespie et al., 2006, with a total of 556 women aged 80 years or older, who underwent to the same progressive muscular strengthening program, balance training and gait training indicate that this intervention decreased the number of individuals that fell during a year, having also reduced the number of injurious falls. Although the studies had methodological limitations, there is a determined consistency as for the decrease of falls in multiple interventions exercises (Gillespie et al., 2009). As for the physical exercise, we only know that it improves balance without a direct association with the decrease in the number of falls (Howe Tracey et al., 2009) and that

although the decline in muscle strength is a risk factor for falls, the muscle strength training could not be associated to the reduced number of falls (Sherrington et al., 2008; Gillespie, et al., 2009).

Few studies take into consideration the importance of the proprioceptive training as a fundamental and unseparable part of a muscular strengthening program. Mechanoreceptors located in the joints, tendons, muscles and neighbor tissue provide information to the Nervous System about the position and articular movements and about the forces generated in the muscles (Hurley, 2003; Van der Esch et al., 2007).

The knee proprioception is essential for the modulation and accurate activation of the muscle contraction, once the functional skill and muscular balance are strongly affected by the proprioceptive inaccuracy and muscle weakness (Van der Esch et al., 2007). Studies including patients with knee ligament lesions show that the proprioceptive training promotes additional sensorial information that contributes to the improvement in postural control (Bonfin et al., 2008). This relationship becomes even more important when the muscle strengthening program aims to improve the functional balance and prevention of falls.

The significant results found in the present research might be explained by the concern in following the ACSM recommendations when prescribing exercises, respecting the basic concepts of prescription exercises.

Additionally, one should take into consideration that the skill to develop muscle strength decreases with aging (Hakkinen et al., 1998) explaining the importance of the gradual progression (Adams et al., 1999). With sedentary elderly people, a period of adaptation and low working load for two weeks should be applied for further implementation of a loading progression protocol (American College of Sports Medicine, 2002).

Teixeira et al., 2010, after eighteen weeks of training, observed an average increase of 87.5% in the maximal dynamic muscle strength in the quadriceps (1-RM) in volunteers in the intervention group, which is similar to the results found by Humphries et al., 2000, showing an increase from 20 to 200% in the dynamic muscle strength of the quadriceps depending on the figures in baseline and time of training. This increased knee extension strength is significantly important since the knee extension strength is an independent risk factor for falls and fractures caused by osteoporosis (Nguyen et al., 1993). The increase in strength results from neural alterations and muscle adaptations (Resende et al., 2008).

The combination of muscle strength and proprioceptive training was fundamental for a research that included postmenopausal women with osteoporosis conducted by Teixeira et al., 2010. The authors found an increase in mobility and functional capacity that might be related to a 36% decrease in time for performing the timed up & go test. We could observe that the shorter the time spent to perform the test, the better the balance (Resende et al., 2008). In this research, Teixeira et al., 2010, observed an improvement in balance evaluated by the Berg Balance Scale, where although there were small numerical changes, it was consistent, agreeing with the outcomes found by Madureira et al., 2006.

Bemben et al., 2000, compared the effects of high and low-intensity training in 25 postmenopausal women (41 to 60 years old) using a high repetition (40% 1-RM, 16 repetitions) and high load (80 % 1-RM, 8 repetitions) protocols for six months showing increases from 30 to 40%, respectively in the dynamic strength in quadriceps.

In a randomized controlled trial of 10 weeks of strength, balance and stretching training in 53 postmenopausal women with osteoporosis, Malmros et al., 1998, showed that strength and muscle mass and also the static balance improved significantly.

In another randomized clinical trial, physiotherapy-directed exercise in 30 patients with osteoporosis significantly improved static balance measured by functional reach and increased quadriceps dynamic strength (Mitchell et al., 1998).

These two studies indicate that the exercises programs improved the profile of fall risk but showed limitations because of the small number of samples and short time of the interventions.

Hartard et al., 1996, studied the effects of muscle strength training in 16 postmenopausal women with osteopenia, where fifteen belonged to the control group. Although they used a small group, a proper load protocol for 6 months, twice a week at 70% 1RM was applied demonstrating a considerable increase in muscle strength ranging from 44 to 76%, with results similar to the ones found in the present investigation.

Kemmler et al., 2002, evaluated the dynamic force (1RM tests) in 137 postmenopausal women with osteopenia divided in two groups and observed a significant increase of 43% in the leg press in the intervention group training at 70% of 1-RM for fourteen months.

Carter et al., 2001, in a program that trains instructors to work with the community selected 93 postmenopausal women with osteoporosis who were randomized and underwent physical exercises of balance and muscle strength for twenty weeks. No improvement in the quality of life was found, which might be explained by the high quality of life at baseline. Researchers observed an improvement of 6.3% in the dynamic balance and an increase of 12.8% in the muscular strength.

On the other hand, Teixeira et al., 2010, showed a significant improvement in the quality of life evaluated by SF-36, where the values (regarding the physical aspects as well as mental aspects) were considerably superior than the controls and values at baseline. These results might be related to the systemic physiologic benefits provided by training, resulting in a better skill to perform daily life activities. We also related these results to the psychological effects of training, socialization with other patients and low initial levels of quality of life.

Madureira et al., 2006, conducted a randomized clinical trial that included 66 postmenopausal women with osteoporosis assigned to two groups. One of the groups underwent a 12-month of balance training once a week combined with oriented training at home showing significant results concerning balance, mobility and decrease in the number of falls.

Swanenburg et al., 2007, studied 24 women (65 years old or older) with osteoporosis or osteopeny who underwent three months of strength, balance and coordination training. After twelve months, they observed a reduction in the risk of fall (Berg Scale) and increase in the muscle strength of lower limbs. They also found a decrease in the number of falls in the intervention group (89%), showing a significant number although it was a pilot study.

As for the reduction of the risk of fall, although it shows an average of 40% (Barnett et al., 2003; Teixeira et al., 2010) it still is not well evidenced, which might be explained by the use of different populations and mainly the interventions used.

Several studies have shown to be effective in increasing the strength, improving the balance and functional capacity and decreasing the risk of falls (Table 2). Only the researches carried out by Madureira et al., 2006, Swanenburg et al., 2007 and Teixeira et al., 2010, directly associate these results and the number of falls demonstrating how effective these interventions were.

Muscle Strength Training				
Author	Period	Method, intensity and volume	Sample	Results
Hourigan, et al., 2008	20-weeks	In this study, subjects were randomised via computer-generated random numbers lists into either a control (receiving no intervention), or exercise group (two one-hour exercise sessions per week for 20 weeks with a trained physiotherapist).	Ninety-eight (98) community-dwelling osteopenic women aged 41-78 years	At the completion of the trial, the intervention group showed markedly significant better performances in balance (unilateral and bilateral stance sway measures, lateral reach, timed up and go and step test) ($p < 0.05$) with strong positive training effects reflecting improvements of between 10% to 71%. Similarly, there were gains in strength of the hip muscles (abductors, adductors, and external rotators), quadriceps and trunk extensors with training effects between 9% and 23%.
Teixeira, et al., 2010	18-weeks	The authors performed a study and randomized the sample into two groups: the intervention group comprised of 50 patients who underwent a 18-week of progressive load training for the quadriceps muscle (50% up to 80% of 1-RM-one maximum repetition) and proprioception training associated to a drug treatment of osteoporosis and the control group that included 50 patients who only underwent a drug treatment of osteoporosis. The muscular strength, balance, functional mobility, and quality of life were evaluated in the beginning and end of the research. The number of falls was evaluated 24 weeks post-treatment.	One hundred sedentary postmenopausal women with osteoporosis, ages ranging from 55 to 75,	The authors found out that the program promoted a significant difference among the groups for SF-36 in the eight sub-scales ($p \leq 0.0018$), Timed Up & Go Test ($p < 0.0001$), 1-RM test ($p < 0.0001$), Berg Balance Scale ($p < 0.0001$) and also a decrease in the number of falls in the intervention group compared to control (IRR = 0.263, 95% CI 0.10-0.68, $p = 0.0064$).
Burk, et al., 2010	8-weeks	The authors randomized the sample into two groups: intervention group, in which exercises for balance and improvement of muscular strength of the inferior members were performed for 8 wks ($n = 17$, age 72.8 +/- 3.6 yrs); control group, which was women not practicing exercises ($n = 16$, age 74.4 +/- 3.7 yrs). At baseline and after 8 wks of treatment, postural control was assessed using a force plate (Balance Master, Neurocom), and muscular strength during ankle dorsiflexion, knee extension, and flexion was assessed by dynamometry.	Sample consisted of 33 women with osteoporosis	When compared with the control group, individuals in the intervention group significantly improved the center of pressure velocity ($P = 0.02$) in the modified clinical test of sensory interaction for balance test, center of pressure velocity ($P < 0.01$), and directional control ($P < 0.01$) in limits of stability test, isometric force during ankle dorsiflexion ($P = 0.01$), knee extension ($P < 0.01$), and knee flexion ($P < 0.01$).

Table 2. Studies that used different methods of muscle strength training

5. Muscle strength training and the use of vibration platform

Although factors as genetic, hormonal homeostasis and nutrition may be affect the bone mineral density, the level of physical activity seems to have an important influence on this variable. The physiological mechanism that explains the osteogenic action of physical activity is not clearly understood. The moment the bone is compressed; negative charges in the place compressed are generated and positive charges in other areas (Figure 4).

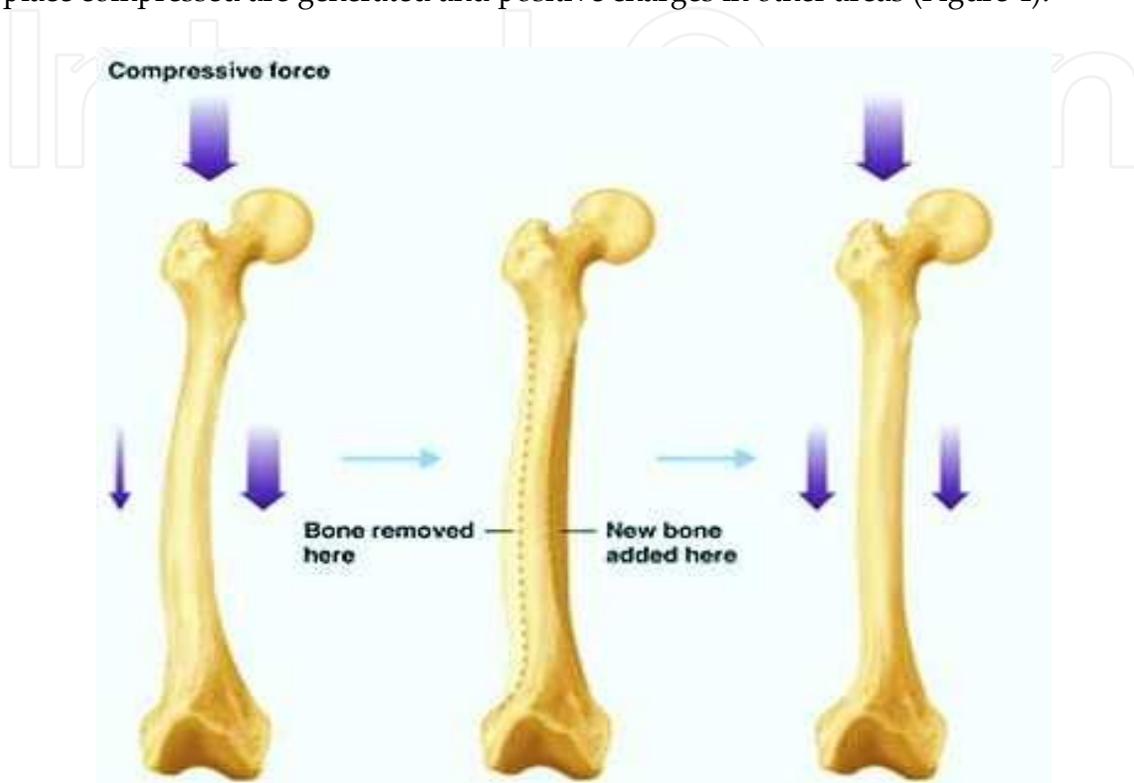


Fig. 4. a) The application of force to a slightly bent bone produces a greater compressive force on the inside curvatures. Compressive force produces weak electrical currents which stimulate osteoblast; b) Over time, bone is deposited in the inside curvature and removed from outside curvature; c) The final result is a bone matched to the compressive force to which it is exposed. Credit: Copyright, Person Education, Benjamin Cumings.

Minimal amounts of electric current stimulate the osteoblasts (bone-forming cells) in the negative extremity that is being compressed, increasing the bone formation in this area (Bankoff et al., 1998).

Another aspect that should be taken into consideration when ideally prescribing the strengthening training in order to stimulate the bone formation is the type of muscle contraction used. In studies comparing the eccentric and concentric strength training with the same relative load, the first showed to be more effective increasing the BMD (Hawkins et al., 1999; Hortobágyi et al., 1996; Aagaard et al., 2000).

The mechanism to increase the bone mineral density (BMD) through the strength training depends on the magnitude of bone deformation caused during this activity. In fact, higher-intensity training related to maximum load is generally associated to greater stimuli for the increase of BMD compared to low-intensity training (Kerr et al., 2001; Vincent & Braith, 2002). Besides that, the use of higher-intensity training implies in more immediate responses in the BMD.

Therefore, it can be concluded that in order to have a strength training providing beneficial effects over bone density, it is important to follow and respect some basic principles of physical training, such as proper overload, volume and intensity. On the other side, this training modality is the one that allows the greatest control of these variables.

5.1 Vibration platform

Vibration platform is a new type of exercise involving the application of a vibratory stimulus to the entire body as opposed to local stimulation of specific muscle groups (Merriman & Jackson, 2009) and has been increasingly tested for the ability to prevent bone fractures and osteoporosis in frail people (Gusi et al., 2006). It has become increasingly popular over the last several year as a form of physical training (Merriman & Jackson, 2009), since it is a non-pharmacological treatment alternative for osteoporosis (Cardinale & Wakeling, 2005). The platform can increase bone strength and bone mass (Sehmisch et al., 2009) since the vibration provides a low level of mechanical load stimulating, therefore the bone remodeling (Hannan et al., 2004). This can be explained by the combined effect on the neuromuscular and neuroendocrine systems (Cardinale & Wakeling, 2005). Vibrational physical exercise causes reflecting muscle contractions like tonic vibration reflex. This type of intervention leads to a high intensive stimulation of proprioceptors called muscle spindles which result in alteration in parameters of activity and development of human physiological functions (Piatin et al., 2009).

The vibrating devices currently marketed show two types of vibrating plates: a) the whole plate oscillates up and down; b) vertical displacements on the left and right side of a fulcrum, increasing the lateral accelerations (Gusi et al., 2006), (Figure 5). The units provide a vibration by using either a rotational or vertical stimulus, that is, the platform rotates about an anterior-posterior axis so that the positioning of feet further apart results in increased amplitude of movement and applies force asynchronously to the left and right foot, similar to standing near the middle of a 'teeter-totter. Vibration units that provide a vertical stimulus have a platform that translates vertically and symmetrically causing simultaneous movement of the lower extremities in the same direction. In addition to the duration of the vibration stimulus, there are several treatment parameters that are important to consider. These include frequency (Hz), amplitude (mm), duration and vibration magnitude (g), which is a gravitational acceleration imposed on the body. However, some studies have used frequencies ranging from 25-50 Hz, amplitudes from 2-10 mm, and total durations of 30 sec – 10 minutes. Currently, there is no consensus regarding the correct parameters needed to achieve a specific physiological response (Merriman & Jackson, 2009). However, some researchers have used frequencies ranging from 15-35 Hz to obtain a maximum transmissibility of the mechanical stimulus produced by the vibratory plate. Some recent studies have included in their protocols 15/10-Hz frequencies to allow a smooth adjustment in individuals considered frail, like the elderly (Gusi et al., 2006).

The effects of this vibration have been studied extensively in occupational medicine, mainly in industrial settings. It has been shown that when the body undergoes chronically to whole body vibrations spinal degeneration is likely to be one of the deleterious outcomes. Symptom of low back pain has been shown to be the leading major cause of industrial disability in the population under the age of 45 years (Cardinale & Pope, 2003).

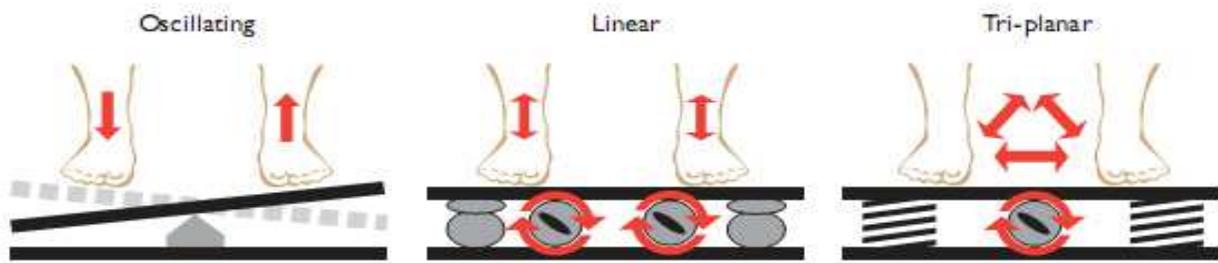


Fig. 5. Three different types of whole body vibration technology, including oscillating, linear and tri-planar platforms. Credit Larry Leggh, PhD and Jonathan Scherer MHK. *J Active Aging*. Nov/Dec 200

In a research conducted by Rubin et al., 2001, in adult rats, they found out that a combination of low magnitude and high frequency vibration significantly increased the anabolic activity of bone, bone density and specifically bone formation.

Studies (Torniven et al., 2003) in animals have shown that the vibrations might be an effective and safe way to improve mass competence and bone mechanic, providing a great potential to prevent osteoporosis.

High frequency (28Hz), very-low-magnitude vibration exercise has recently been reported to increase bone mass in experimental animals and in humans (Russo et al., 2003). Therefore, in order to obtain bone reinforcement, the frequency and amplitude of vibration should not exceed specified levels for the treatment. Furthermore, low-frequency vibration does not stimulate the bone sufficiently to cause significant remodeling (Aleyaasin & Harrigan, 2008). Fractures are among the commonest and most expensive health problems in the elderly population, therefore the physical exercise is considered an effective and frequently recommended strategy. However, hard bone stress induced by the vigorous activity of weight bearing might increase the risk of lesions (Gusi et al., 2006; Gilsanz et al., 2006).

Although evidence is overwhelming that physical exercise positively affects muscle strength at all ages, compliance of older persons with traditional exercise programs is low, and only a small percentage of older persons exercise regularly (Russo et al., 2003). According to Liu et al., 2011, osteoporosis and its associated fractures are common complications of aging and that the purpose of most therapeutical strategies is to prevent and/or treat bone loss focused on nonpharmacological approaches. Therefore, aerobic exercise and/or whole-body vibration (WBV) might have beneficial effect on bone mass and provide an alternative approach to increase or maintain bone mineral density and reduce the risk of fracture (Table 3).

However, the mechanism through which the vibrations influence the bone tissue is still obscure. There is a lack of understanding the physiological mechanisms involved in the adaptive responses or the most appropriate vibration parameters to be used in order to maximize gains (Santin-Medeiros & Garatachea, 2010; Cardinale & Rittweger, 2006). The high-frequency postural displacements induced by the alternating movements of the platform produce reflex muscle contractions aimed at stabilizing posture. Thus, vibration can be viewed as a special form of muscle training that may particularly affect muscle power. It has been proposed that the force applied to bone during muscle contraction has a pivotal role in the homeostatic and adaptive regulation of bone strength (Russo et al., 2003). However, researchers (Torniven et al., 2003) carried out a study with the vibration platform and concluded there was no effect on the bones of young and healthy adults.

Whole-body vibration				
Author	Period of time	Method, intensity and volume	Sample	Results
Verschuere, et al., 2004	The WBV group and the RES group trained three times weekly for 24 weeks	The authors performed this randomized controlled trial to assess the musculoskeletal effects of high-frequency loading by means of whole body vibration (WBV) in postmenopausal women.	Seventy volunteers (age, 58-74 years) were randomly assigned to a whole body vibration training group (WBV, n = 25), a resistance training group (RES, n = 22) or a control group (CON, n = 23)	The authors found out that vibration training improved isometric and dynamic muscle strength (+15% and +16%, respectively; $p < 0.01$) and also significantly increased BMD of the hip (+0.93%, $p < 0.05$). No changes in hip BMD were observed in women participating in resistance training or age-matched controls (-0.60% and -0.62%, respectively; not significant). Serum markers of bone turnover did not change in any of the groups.
Slatkowska, et al., 2010	Follow-up of ≥ 6 months	The authors performed a systematic review and meta-analysis where eligible RCTs included randomized or quasi-randomized trials, with follow-up of ≥ 6 months, examining WBV effects on BMD in ambulatory individuals without secondary causes of osteoporosis. The weighted mean differences between WBV and control groups in absolute pre-post change in spine and hip aBMD, and in spine and tibia trabecular volumetric BMD (vBMD) were calculated.	Eight RCTs in postmenopausal women (five RCTs), young adults (one RCT), and children and adolescents (two RCTs) were included. The regimens were heterogeneous, study durations were relatively short, and available data was mostly per-protocol.	In postmenopausal women, WBV was found to significantly increase hip aBMD (0.015 g cm ⁻² ; 95% confidence interval (CI), 0.008-0.022; $n = 131$) versus controls, but not spine aBMD ($n = 181$) or tibia trabecular vBMD ($n = 29$). In young adults, WBV did not increase spine or hip bone mineral content, or tibia trabecular vBMD ($n = 53$). In children and adolescents, WBV significantly increased spine (6.2 mg cm ⁻³ ; 95% CI, 2.5-10.0; $n = 65$) and tibia (14.2 mg cm ⁻³ ; 95% CI, 5.2-23.2; $n = 17$) trabecular vBMD.

Table 3. Studies that used whole body vibration (WBV)

In a systematic review (Merriman & Jackson, 2009) conducted about the vibration platform to understand the effects on bone density, muscle performance, balance, and functional mobility in older adults concluded that most of the studies is methodologically weak and should be interpreted with caution. The study protocols use widely variable parameters which make the study interpretation difficult. The effects of this long term vibration (>1 year) still need to be studied. Some but not all of the studies in this review reported that individuals exposed to those vibrations showed similar improvements in muscle performance, balance, and functional mobility as compared to traditional exercise programs and that the vibration platform does not provide any additional benefit. Bone studies consistently showed that WBV improved bone density in the hip and tibia but not in the lumbar spine. Additional studies are needed to determine safe and effective parameters for WBV training in older adults.

However, the treatment has to follow specific safety guidelines to prevent vibration exercise-related injuries, such as limiting the exposure to vibration to a maximum of 10 minutes and maintaining a good posture of the participant.

Due to a great controversy in studies on its effects and parameters, more studies in humans with specific clinical recommendations and protocols are necessary for the vibration training (Gusi et al, 2006; Torniven et al., 2003).

6. Conclusion

Physical activity is an essential factor in bone health. The benefits of exercise have been demonstrated throughout the life cycle. Exercise can positively affect peak bone mass in children and adolescents; has been shown to help maintain or even modestly increase bone density in adulthood and; can assist in minimizing age related bone mass peak loss in older adults. Physical exercises that cause mechanical stress are the most recommended to increase or keep bone mass. However, the prevention of falls seems to be the most important factor in decreasing the risk of fractures in women with osteoporosis and in elderly people, since more than 90% of hip fractures results from falls.

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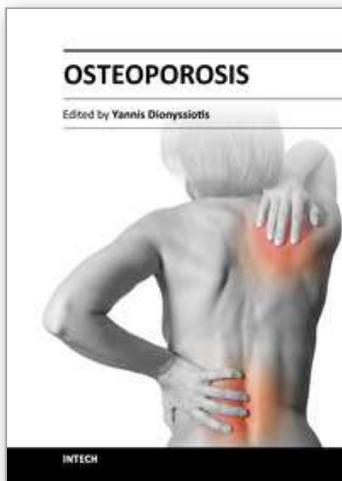
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Osteoporosis is a public health issue worldwide. During the last few years, progress has been made concerning the knowledge of the pathophysiological mechanism of the disease. Sophisticated technologies have added important information in bone mineral density measurements and, additionally, geometrical and mechanical properties of bone. New bone indices have been developed from biochemical and hormonal measurements in order to investigate bone metabolism. Although it is clear that drugs are an essential element of the therapy, beyond medication there are other interventions in the management of the disease. Prevention of osteoporosis starts in young ages and continues during aging in order to prevent fractures associated with impaired quality of life, physical decline, mortality, and high cost for the health system. A number of different specialties are holding the scientific knowledge in osteoporosis. For this reason, we have collected papers from scientific departments all over the world for this book. The book includes up-to-date information about basics of bones, epidemiological data, diagnosis and assessment of osteoporosis, secondary osteoporosis, pediatric issues, prevention and treatment strategies, and research papers from osteoporotic fields.

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