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Titolo della tesi

**VIBRATION ENERGY: TRAINING METHOD AND
NEUROMUSCULAR ASSESSMENT**

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Abstract

Purpose: A new training method based on vibration energy applied to the whole body produce changes on gravitational conditions with consequently specific effects on neuromuscular, osteo-articular and endocrine system. Aims of this study concerns, after a deep scientific review about the effects on biological system, to investigate the effects of vibration energy related to the bone tissue in a sample of osteoporotic female and the possibility of hits application in the clinical investigation of neuromuscular function as during post-surgery rehabilitation period in patients operated of Anterior Cruciate Ligament (ACL).

Methods: in the present thesis are presented two experimental study.

Study 1. This study regard the effects of vibration energy in twelve osteoporotic females after 4 months of treatment. The experimental group improved the Amplitude-Dependent Speed of Sound (AD-SoS) QUS parameter from $1.878 \pm 79,45$ to $1.971, 17 \pm 78,69$ ($p < 0,002$), the T-score passing from $-3,50 \pm 1,13$ to $-2, 18 \pm 1,12$ ($p < 0,002$) and the Ultrasound Bone Profile Index (UPBI) improve from $0,34 \pm 0,11$ to $0,47 \pm 0,21$ ($p < 0,01$). In the control group (low impact exercise) any of these parameters considered show significantly changes over the same period of time.

Vibrations energy stimulated an increase in bone density and strength in animals and humans. This strongly anabolic, non-invasive intervention represents, associated to good physical fitness also, early evidence of an unique non-pharmacologic treatment for osteoporosis.

Study 2, This study is direct to evaluate the vibration energy as assessment method in rehabilitation field, specifically direct to ACL operated patients after with a follow-up from the surgery intervention about 3,5 months.

During isoinertial test the I velocity ($p < 0,002$), the displacement ($p < 0,004$) was lower, while the sEMg activity of vastus lateralis and

medialis ($p < 0,003$) was higher than the non-operated leg. The EMG activity monitored during vibration treatment was much higher in the operated compared to controlateral-one ($p < 0,02$).

The assessment of biomechanical parameters associated to sEMG activity in isoinertial dynamic and vibration test, represented by the comparison of operated/non-operated, showed to be an effectiveness clinical method of assessment the neuromuscular behaviour of the operated limb in different exercise regimen.

Conclusion The physical exercise is the only means, capable to counteract this degeneration process is the functional mechanical stimulus. In this contest the vibration energy represent a safe and healthy training method, effectiveness for its easy application in terms of time treatment and operability. Moreover, the response of neuromuscular system to vibration, analysed trough the use of sEMG, is an important assessment method. Associated to isoinertial test integrated with sEMG, actually is the only system capable to give information on neuromuscular strategies in post-operated subject.

Key Words: Vibration – Neuromuscular Assessment – Bone – Training – sEMG.

Introduction

The responses of mammals to environmental changes inevitably involves in specific adaptations of biological systems much more stimulated. The musculo-skeletal system is a very complex biological machine that function to support and move the body. Bones, joints and muscles actively change in structure and metabolism to meet various mechanical demands placed on the system. These systems interacts and respond to patterns of environmental ipergravity, like weight lifting exercise, or ipogravity conditions, like bed rest or microgravity exposure (experienced from astronauts during space mission), with major alteration in structure and strength. These changes involves as the muscle system than the bone tissue that receive stimuli from the muscles trough tendons and ligaments. The structure and growth of bones are genetically determinates excepted for density, mass and final architecture that changes in function of daily mechanical stress (34). Then, the interaction between the human been and the gravitational mechanical stimulus, represented by the daily habitual movements, produce structural and metabolic changes direct to maintain the whole osteo-muscle-articular system in functional conditions. Besides, the human locomotion, represent the lowest mechanical stimulation which ensures the basic muscular tone. This stimulus, which is generally required to win gravitational force, it is enough to protect the bones from injuries and fracture. In fact, during locomotion, in the ground contact phase, a train of vibrations are generated and transmitted along the body, travelling in form of impact waves from the foot, to the head throughout the legs, the spine and the skull. These impact waves represents the main osteogenic stimulus during the life of human been. Sedentary life style and hypokinesia, typical characteristics of industrialised countries, are the principal causes of degenerative diseases like diabetes, osteoporosis, etc. that affects a large number of ageing people. Epidemiological studies shows the importance of an

exercise training regimen to counteract the effects of hypokinesia on muscle-skeletal system (25, 40, 41, 48, 67). Recently, a new training method based on vibration energy applied to the whole body produce changes on gravitational conditions with consequently specific effects on neuromuscular, osteo-articular and endocrine system (1, 6, 7, 8, 12, 50, 51, 72, 73) . Aims of this study concerns, after a deep scientific review about the effects on biological system, to investigate the effects of vibration energy related to the bone tissue in a sample of osteoporotic female and the possibility of hits application in the clinical investigation of neuromuscular function as during post-surgery rehabilitation period in patients operated of Anterior Cruciate Ligament (ACL).

REVIEW OF THE LITERATURE

1. Effects of Vibration Energy on Bone Tissue

Osteoporosis is currently the major cause of in older people, with most severe consequence at hip level. The prevailing view is that the major determinant of fracture risk is the bone mineral density (BMD) (18, 19). The risk of hip fracture is approximately doubled for every standard deviation reduction in BMD (33). Thus to maximize the peak bone mass and maintain bone mass or decrease bone loss would reduce the fracture risk of elderly people. Several study indicates that physical activity is effective in improving and maintain bone mass and strength and thus in preventing osteoporosis fractures (40, 41, 67). The basic form and development of skeleton is genetically determined, but hits final mass and architecture are governed by an adaptive mechanism sensitive to the mechanical gravitational environment. According Wolff's law (1892) (74), the bone functionally respond to the habitual stress imposed upon it. Following this concept, Frost in 1987 (26) proposed his mechanostat theory to explain the architecture and mass bone adaptations to its typical mechanical environment trough different biological process within strain ranges (loading-induced deformation in bone tissue) or thresholds for bone modelling and remodelling drift, supporting the biological bases of physical exercise effects on bone tissue (48).

1.1 Bone Tissue Properties

Bone is a structural and a metabolic tissue formed of 24% organic matrix, composed primarily of proteins, glycoproteins, polysaccharides, type I collagen fibres, noncollagenous protein, and of 76% by inorganic salts conferring rigidity and consistence to be differ from other connective tissue (2). This characteristics allow it to supports the body

against gravity, to provide a lever system and mechanical function for body motion, to protect soft tissues of internal organs and bone marrow, to take part in mineral, especially calcium, homeostasis and haematopoiesis.

The bone architecture consists for 80% of whole skeletal mass of a cortical structure, dense solid mass with only microscopic spaces and channels that cover externally the bone, whereas internally for the remaining 20%, of a trabecular structure formed by a bee nest scaffolding, with plates and arches, more metabolically active but less rigid than the cortical one (2, 13, 38). In the long bones, the diaphysis is primarily compact in structure, whereas the epiphysis and metaphysis are mainly filled with trabecular bone. The interaction among organic matrix, inorganic salts, cylindrical shape of cortical bone and trabecular structure, confers to the bone structure the maximum mechanical support with minimum mass (20, 42). The bone structure and shape warrants strength in relationship to load bearing stress (20, 52).

1.2 Bone Turnover

During the individual life the bone tissue changes proper structure, shape, density and strength in function of his daily activity and load borne, through three biological mechanisms with different specific functions: the growth, that influences the dimension, the modelling, that influences the shape, and the remodelling, that influences the specific adaptation (3, 26, 27).

The *growth* of skeletal system is due from the interaction between genetic factors and mechanical stress, and modified by nutritional and hormonal aspects. During this phase the activation of muscle and weight-bearing exercise constitute a mechanical environment that induces the cellular activity to achieve and maintain the normal architecture, shape and size of the skeleton. This sensibility of bone tissue to mechanical stimuli, in the growth phase, may have important consequences on bone mass density later in the ageing (4, 25,

46). In effects, the BMD in the elderly people depends as of peak bone mass, that in human been is achieved around at age of 20 years, than of the rate of bone loss underwent (5, 22, 40, 55).

The *modelling* process is defined as simultaneous removal and formation of bone at different sites operate from two mediator mechanisms related to drift cells as osteoblasts, with the formation drifts add new bone, and osteoclast, with the resorption drifts remove bone over broad surface region (26, 29). The osteoblasts also, has an important role on the balance control of inflow and outflow of calcium ad others minerals. In the modelling process Frost (29) recognised two different sub group processes distinct for specific activity. The *Micromodeling* organize the cells and collagen during heir formation to determine the kinds of tissue being formed and thicken and rearrange the individual trabeculae (42, 44) The *Macromodelling* that control the gross shape, size, strength, add new bone at the periosteum and endosteum, and anatomy of joints, bones, tendons and other organs. Modelling process increase the bone strength by improving geometric properties and adding mass (42).

The *Remodelling* process is defined as the removal of old and the formation of new bone at same site at different time and repairs micro cracks (70). In a normal adult person, activation and resorption last one month and formation another three months, thus the time scale for one complete remodelling cycle, called sigma, occurs about 4 months (28, 38) while for one complete mineralisation occur in another three to four months (38). This process can be regulated by different factors as mechanicals as hormonal (steroids, thyroids hormones) and local factors (prostaglandins, growth factors). In disuse conditions of bone structure, like those experienced in ageing, the remodelling process is associated more to resorption than formation drafts (39).

1.3 The Biomechanical properties of bone tissue

The chemical and structural composition of bones determine two important quality like strength and rigidity. The structure strength can be defined as the load magnitude at the failure points or as the ultimate load supportable and depend of its size (21, 47), whereas, the rigidity is defined as the linear deformation capacity of structure submitted to increasing external loads. The deformation of structure bone is can be measured and plotted on a load-deformation curve and the stiffness or rigidity can be determined as slope of the linear part of this curve (Fig. 1), better know as elastic modulus or Young's modulus. The physiological significance of this aspect is due to the fact that forces applied to the bone at any point to along this curve will only deform the bone temporarily and, after removed the load, the structure returns to its original state (21).

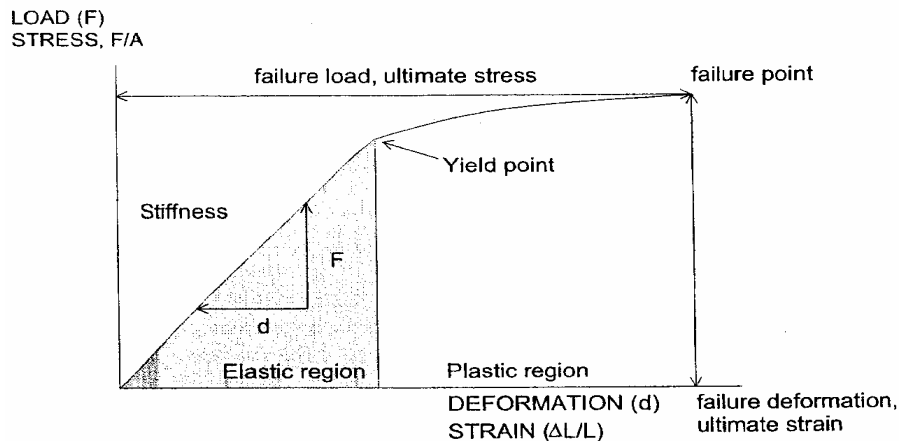


Fig. 1 Load – Deformation Curve

The central structure of long bone is naturally designed to act the greatest stiffness in the direction of long axis and greatest impact loading resistance occurs in the transverse direction. The biomechanics property of bone tissue, on hits continuous adaptation process, depend upon two fundamental concepts that define the properties of bone without the geometric effects: stress and strain.

Stress is represented by an internal resistance in bone generated to react the external force (equal and opposite) applied per unit area and it can be classified as compressive (produced when two force are directed toward each other along the same line and as consequence the material is shortened), tensile (produced when two forces are directed along the same line but away from each other and as consequence the material is stretched) or shear (when two force are parallel to each other but not along the same line as consequence the material is bent or torque) (fig). The measure unit of stress is 1 Pascal that is equivalent to a force of 1 N (Newton) acting over an area of one square meter. In nature this three types of stress can act alone or in combination. In addition to the forces which arise during daily activity, the skeleton may be subjected to impact force trough which collision, falls and other accidents. The concept of strain is referred to ratio between stress and structure stiffness. In other words, strain regard the deformation in shape an size the bone experienced under the influence of an applied load and it is reported as the changes in length of a material divided by the its original length (fig) (34, 71).

In the Frost “mechanostat theory “ the strain concept was utilised for to establish the threshold of minimum effective strain (MES) beyond which the bone tissue need to be stimulated to maintain functional homeostasis (26, 27, 29, 31). Loads inducing local strain with a magnitude comprise in a range of 1500 2500 microstrain, stimulates the modelling process with anabolic response of bone tissue, whereas mechanic stimuli under a range of 100-200 microstrain, primes the remodelling process with consequent bone resorption. (Fig. 2)(17, 29, 44).

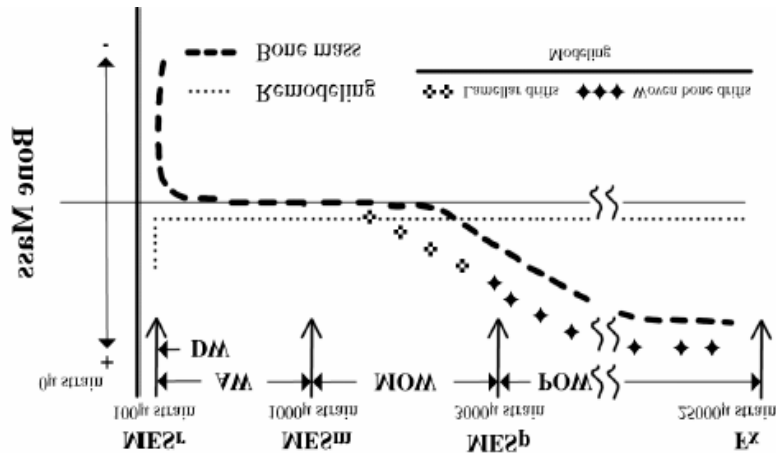


Fig. 2 Diagram illustrating the relationship of strain and adaptive responses

1.4 Effects of Physical Exercise on Bone Tissue

The physical activity represent the principal mechanical stimulus in the regulatory process of modelling and remodelling process of bone tissue. However, the type, intensity, frequency and duration of exercise and the interrelationship that each of these variables has in terms of strain magnitude, strain frequency and strain intensity applied at bone tissue level to provide an optimal anabolic response are still largely unknown (34). In effects, the physical activity for to produce effects on the bone modeling process must be capable to generate adequate strains to bone level, not only from quantitative, but also from qualitative point of view, in terms of frequency and intensity. All these variables are integrated to each other on dynamic interactions of mechanical stimuli. Low magnitude strain to frequency level comprise between 15 – 30 Hz, typical frequency range of walking, represent a critic level for to prime an anabolic response of bone tissue. For to obtain an effective anabolic stimulus a the same frequency it need to increase the frequency (62). This aspects suggest that for a functional physical training regimen able to stimulate modelling process of bone structure must be programmed combining the variables of magnitude, intensity and frequency to obtain an enough level the mechanical stimulus.

Moreover, spatial strain distribution play a effective role in formation process of new bone, For this reason, the mechanical stimulus must be

applied with different type of movements, in relationship to a spatial strain distribution in different directions. In fact, different training regimen produce different loading characteristics of the skeleton (34). In this way, as an heavy resistance training or another type of mechanical stimulus of variable in intensity, characterised from movements performed in different directions, like in dance or in gymnastics, are able to determine specific anabolic response of bone tissue (34).

1.5 Vibration Energy as Osteogenic Intervention

Recently, in light of positive effects that vibration energy determine in muscular system, the whole body vibration has received hits scientific attention about the possible anabolic effects on bone tissue. Recent clinical studies have suggested that the whole body vibration represents a mechanical stimulus enough to improve the muscular performance (6, 7, 12, 36, 37, 50, 58). The interaction between muscle and bone responds to patterns of use or disuse with relative alterations in structure and strength (35, 66). Moreover, as show scientific evidence show that load applying loads at 30 Hz of frequency necessitate only 50 microstrains to stimulate bone formation (56). The whole body vibration has been shown to effectively counteract bone loss. The first clinical studies was conducted on animal model. Flieger in 1998 (24) showed that applying the mechanical stimulus at 50 Hz of frequency and 2 g of magnitude for 30 min per day for 12 weeks on ovariectomized rats, the bone loss was less than the other rats not exposed to vibration stimulus. Rubin et al. (63) exposed, first a mature turkey stimulated on vibrating platform, oscillating at 30Hz, 0,3 g of magnitude ($g = 9,81$) for 5 minutes per day for 30 days of treatment showing an increase of new bone formation in the trabecular bone of the distal tibia. Continuing on their animal studies, Rubin et al. (64) showed that applying stimulated at 30Hz for 20 minutes per day, it is obtained a 34% of increase in the density of trabecular bone in the proximal femur of adult male sheep following one year of treatment. Oxlund (51) found that an oscillating

frequency of 45 Hz was enough to increase bone formation and preserving biomechanical bone strength on ovariectomized rats. The first clinical studies on human been show a positive effects in adolescents with cerebral palsy (73) and in osteoporotic female (54). Recently other authors show the increase as in muscle strength than in bone mass after exposition to vibration stimulus in post-menopausal women. Rubin (65) showed an improvement bone mass density (BMD) of 1,5% in the spine and 2,17% in the femur, whereas the control group lost 1,6 % in the spine and 2,13% in the femur, in postmenopausal women submitted at Whole Body Vibration (WBV) treatment at 30 Hz of frequency for 20 min (2 bouts of 10 min) per day, every days for 12 months. Improvements on BMD and on muscular strength was found also after six months of WBV treatment at 35-40 Hz of frequency and 5 g of magnitude (72). These results seems to suggest that this intervention may have an anabolic effect on bone tissue. In contrast, the modest physical activity at low impact doesn't have any effect on BMD of postmenopausal woman (68).

2. Effects of the Vibration Energy on Neuromuscular System

The vibration energy is a mechanical stimulus determined by a sinusoidal oscillatory motion that through its parameters of frequency (cycles per second measured in Hz), amplitude (peak to peak displacement in mm) and magnitude (acceleration measured in m/s^2 or multiple of g , where g is the gravitational acceleration equal to $9,81 m/s^2$) generate the neuromuscular response. The vibration energy can be applied to the body in different ways. Locally directly on tendons or on muscle bell using vibration cable (36, 37) or vibrating dumbbell (8) and generating a typical neuromuscular response, called "tonic vibration reflex" (TVR). In the other method the vibration energy is generated by vibrating plate where the subject is positioned in standing position bent legs at suitable angle knee. In this case the vibration energy travel along the body, from feet to the head, generating the TVR in all body muscles with decreasing intensity to increase the distance from the vibrating plate. This method in scientific literature is defined "Whole Body Vibration" (WBV). In both methods the vibration provides a perturbation of gravitational field during the time-course of exposure determine an increase of muscle strength and power (6, 7, 8). It has long been reported that mechanical vibration influence positively the normal function of muscle and tendons (32, 50) and recently has aroused interest not only in research field but also in exercise physiology, as a potentially very efficient training method for musculo-skeletal system, inducing improvements similar to those observed with heavy resistance training (6, 7, 9, 10). These effects, probably are related to the characteristics of hyper gravity imposed by vibration that are similar to those experienced from neuromuscular system during plyometrics or extralloads exercises. Besides, vibration energy change the gravitational field due to high acceleration (from 0,5 to 14 g) (16). The neuromuscular response to this hyper gravity condition characterised by fast, shorts and frequently micro contractions following the stretch-shortening cycle. This perturbation is

detected by the sensory receptors that modulate muscle stiffness through reflex arc mediated from the activation of mechanoreceptors (Muscle spindles) that leading to an enhancement of the stretch-reflex loop determine the reflex activation of α motor neuron. This phenomena is observable from the increase in surface EMG activity during vibration exposure more than 100% than the one observed during the same voluntary muscular activity (8). This neuromuscular behaviour can be mediated not only by monosynaptic but also by polysynaptic pathway (14). Mechanical vibration is perceived not only by muscle spindle, but also by the others proprioceptors (Mazzoni, Pacini, Ruffini, Golgi, etc.) presents in the tendons skin, ligaments and joints (57). The increase in neuromuscular performance after acute and prolonged vibration treatment is probably connected to an increase in the sensitivity of the stretch-reflex (45). Moreover, vibration stimulus seem to inhibit activation of antagonist muscles through Ia inhibitory neurons altering the intermuscular coordination patterns leading to a decreased force in those muscles. This effects probably is the main factor determine an increase as explosive power and maximal dynamic strength of leg extensors muscles that an increase of flexibility of the hamstrings (12).

Moreover, it need to consider the connection between the afferent signals, and their central processing unit, constituted by primary and secondary somatosensory cortex, supplementary motor area and area 4a of the brain that, all together activated by vibration energy, influences the excitatory state of peripheral and central structures, producing kinesthetic illusion and facilitating subsequent voluntary movement (49).

In effect, many study show the post vibration improvement of vertical jumps, dynamic strength in its force-velocity and power velocity relationship as acute effect (7) that after a prolonged treatment (1, 69) (Fig. 3)

In synthesis, the vibratory energy stimulate different sensory structures that through the spinal loop and a sub-cortical and cortical involvement, produce a reflex muscle activation with the response of

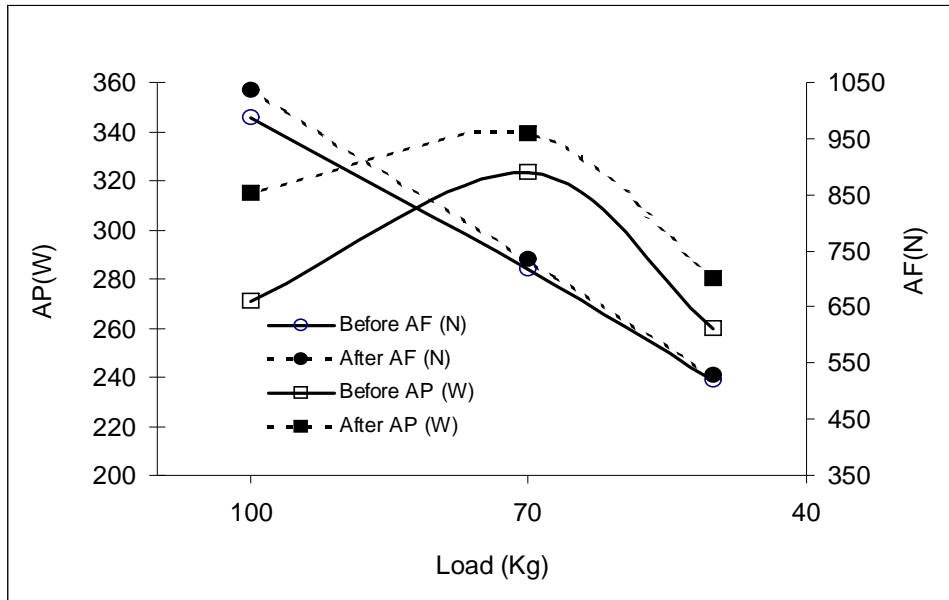


Fig. 3 Average power (AP) and average force (AF) developed during leg press exercise performed with progressive loads (50, 70, and 100 kg) are shown before (open symbol) and after (filled symbol) the WBV training.

neuromuscular system more powerful and effective than voluntary activation.

2.1 Vibratory Energy as Neuromuscular System Assessment

In the last years the assessment of neuromuscular behaviour has received a powerful input from the evolution of technological systems with a consequent improvement of new instruments and devices dedicated mainly to the sport science and rehabilitation field. However, the assessment of the neuromuscular function is so far to be enough complete for understanding the complex adaptations phenomena of biological transformations consequently to the injuries or/and after surgery. Besides, there is an high percentage of patients showing a weakness or muscle impairments or dysfunctions of leg extensors muscles after a long follow-up period, probably due to proprioceptors perturbation caused from surgery intervention (23). At moment, the

standard protocol used in rehabilitation field for evaluate the legs muscle impairment regards the assessment of muscle strength of both legs in isometric or isokinetic contraction. Both methods present evident limits regarding the unspecific muscle contraction modality, static the first and unnatural contraction type the second and in both cases the sensory structures deputed to be activated by the variation of velocity (like pacinian corpuscle) aren't stimulated without contribute to muscle force output. These limits are exceeded by the isoinertial dynamometry that measure the biomechanics parameters of muscle contraction (force, velocity, displacement and power) in dynamic and against gravity following the natural property of neuromuscular contraction (11). Unfortunately, the isoinertial method also is inadequate and lack of specific evaluation technique that could allow the quantification and assessment of the impairment due to the proprioceptors inability to function properly consequently to the injuries or surgery intervention. In this contest of paramount importance was the first pilot investigation, conduced by the Prof. Carmelo Bosco and Rehabilitation Medical Equip of "Tor Vergata" University of Rome directed by the Prof. Foti, to analyse the possibility for detecting and quantifying the operated knee joint proprioceptors functional capacity introducing for the first time, the vibratory energy in the neuromuscular assessment field (11). This method consist on monitoring the electromyography activity of muscle during vibration for to identify altered neural strategies of motoneuron pool recruitment. In effect, an increase in EMG activity is usually observed during vibration treatment with values higher that ones observed in voluntary muscle activity (8, 59, 69) (Fig. 4).

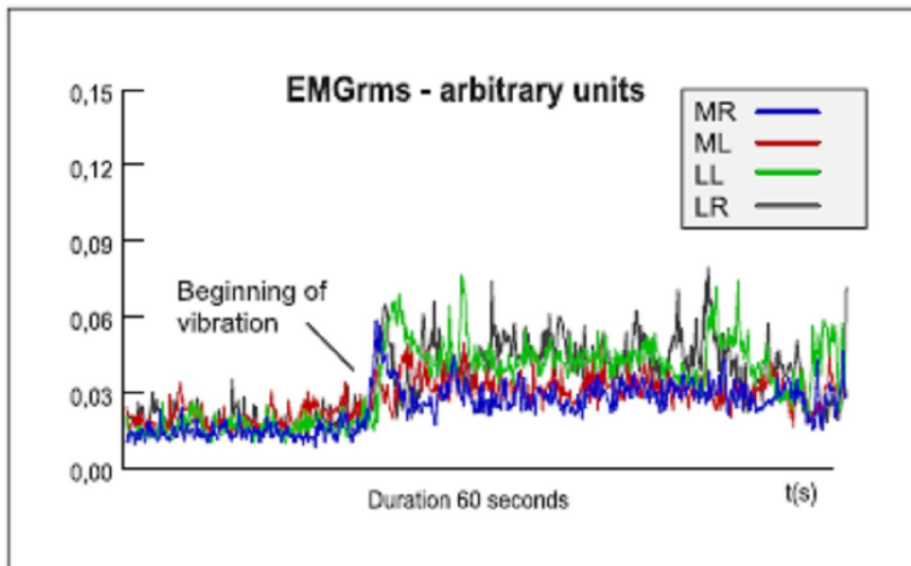


Fig. 4 Electromyographic activity (EMGrms) recorded from leg extensor muscles (mm. vastus lateralis : LR and LL and medialis : MR and ML of both left and right legs), before and during whole vibration treatment.

It was suggested previously the possibility that vibration may elicit excitatory inflow through muscle spindle – α motoneuron connections in the overall motoneuron inflow (45). It has been shown that vibration generate an enhancement of the stretch-reflex loop determine the reflex activation at spinal level of α motoneuron without descending motor drive (59). In addition, it has been demonstrated that vibration energy-induced activation of muscle spindle receptors, not only in the muscle to which vibration was applied, but also to the neighbouring muscles (43). In light of above findings, actually the vibration energy in hits two application ways, locally on the muscle bell or to the whole body, it can retain a new assessment strategy to identify neuromuscular behaviour and possibly dysfunction associated to assessment isoinertial method synchronised with EMG.

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STUDY I

The effects of low-frequency high-magnitude whole body vibration in physical actively osteoporotic women: a pilot study.

Abstract

Purpose: Osteoporosis is nowadays affecting a large population. Recent studies, performed on animals and human been, have shown that low magnitude, high frequency mechanical stimuli produce anabolic effects on bone tissue, increasing both bone density and strength. Aim of this study is to verify the effects of whole body vibration on bone tissue of trained osteoporotic women underwent to high magnitude and high-frequency vibration exercise on a vibrating platform.

Method: Twenty-six osteoporotic women, trained with low impact exercise regimen, voluntarily participated in the study and were randomly divided in two groups: experimental (E) and control (C). All subjects aren't submitted to any pharmacological therapy. The T-score, Ultrasound Bone Profile Index (UPBI) was calculated using the Amplitude-Dependent Speed of Sound (AD-SoS) measured with QUS.

Results: Thirteen osteoporotic women following four months of ten-minute treatments, three per week, of high-level of magnitude (5,0 g) and high frequency (30Hz) mechanical vibration improved the Amplitude-Dependent Speed of Sound (AD-SoS) QUS parameter from $1.878 \pm 79,45$ to $1.971, 17 \pm 78,69$ ($p < 0,002$). The T-score in the experimental group show an inversion trend passing from $-3,50 \pm$

1,13 to $-2,18 \pm 1,12$ ($p < 0.002$) and the Ultrasound Bone Profile Index (UPBI) improve from $0,34 \pm 0,11$ to $0,47 \pm 0,21$ ($p < 0,01$). In the control group (low impact exercise) any of these parameters considered show significantly changes over the same period of time.

Conclusion: Given that these accelerations were well tolerated by the experimental cohort, that vibrations similar to these stimulated an increase in bone density and strength in animals and humans, and that skeletal loading is an inevitable product of functional load bearing, we believe this strongly anabolic, non-invasive intervention represents, associated to good physical fitness also, early evidence of an unique non-pharmacologic treatment for osteoporosis.

Introduction

Osteoporosis is currently affecting a large population. Over 40% of women in the United States over the age of 65 are currently affected, determining a cost, which exceeds \$15B per year to the health care services [1]. According to the E.S.O.P.O. study (Epidemiological Study On the Prevalence of Osteoporosis) in Italy 23% of women older than 40 years and 14% of men older than 60 years are affected by osteoporosis [2].

Many different prevention and treatment regimens have been developed to resolve the increasing problem of the osteoporosis and related fractures. Reversal of bone loss is then a critical goal for science for improving the long-term well being of the aged population. Several investigations have been conducted trying to identify an effective countermeasure to osteoporosis. However, while several pharmacological interventions have been implemented for the management of this disease [3, 4, 5, 6], it seems that sometimes the risks connected to the side-effects exceed the apparent benefits [7]. Several authors showed that the mechanical stimulus, mediated by physical activity or exercises, is the only mean which can positively influence not only the bone mass and strength but increasing muscle strength too [8, 9, 10, 11]. In addition, regular physical activity enhances health and physical fitness improving overall the quality of life in elderly population by reducing the risk of deterioration of functional capacity [12, 13]. Moreover, the osteogenic adaptation of skeleton is site-specific and related to training regimens [14, 15]. Scientific evidence shows that low impact type movement, like endurance training, has not significant results in bone gain [11]. Therefore, the impact type movement, that generates a

versatile stimulus on whole muscle-skeletal system can generate osteogenic adaptation on skeletal sites [14]. In fact, according to Wolff's law (Wolff, 1892) [16], the bone tissue is constantly adapting to changes in its loading environment accommodating the structures of the skeleton to mechanical demands. The loading-induced deformation in bone tissue (strain) are responsible for the adaptations in bone architecture and mass [17, 18]. The mechanical strain, for determining the effects on bone remodelling, is related to the other specific factors like magnitude, frequency and application time [19, 20]. Changes of gravitational conditions can be produced also by varying magnitude and frequency of mechanical stimulus, like mechanical vibrations applied to the whole body [21]. Recent clinical studies have suggested that the whole body vibration represents a mechanical stimulus enough to improve both the muscular performance [21, 22, 23, 24]. The interaction between muscle and bone responds to patterns of use or disuse with relative alterations in structure and strength [25, 26]. The whole body vibration has been shown to effectively counteract bone loss. The first clinical studies were conducted on animal models. Flieger in 1998 [27] showed that applying the mechanical stimulus at 50 Hz of frequency and 2 g of magnitude for 30 min per day for 12 weeks on ovariectomized rats, the bone loss was less than the other rats not exposed to vibration stimulus. Rubin et al. [28] exposed, first a mature turkey stimulated on vibrating platform, oscillating at 30Hz, 0,3 g of magnitude ($g = 9,81$) for 5 minutes per day for 30 days of treatment showing an increase of new bone formation in the trabecular bone of the distal tibia. Continuing on their animal studies, Rubin et al. [29] showed that applying stimulus at 30Hz for 20

minutes per day, it is obtained a 34% of increase in the density of trabecular bone in the proximal femur of adult male sheep following one year of treatment. Oxlund [30] found that an oscillating frequency of 45 Hz was enough to increase bone formation and preserving biomechanical bone strength on ovariectomized rats.

The first clinical studies on human been show a positive effects in adolescents with cerebral palsy [31] and in osteoporotic female [32]. Recently other authors show the increase as in muscle strength than in bone mass after exposition to vibration stimulus in post-menopausal women. Rubin [33] showed an improvement bone mass density (BMD) of 1,5% in the spine and 2,17% in the femur, whereas the control group lost 1,6 % in the spine and 2,13% in the femur, in postmenopausal women submitted at Whole Body Vibration (WBV) treatment at 30 Hz of frequency for 20 min (2 bouts of 10 min) per day, every days for 12 months. Improvements on BMD and on muscular strength was found also after six months of WBV treatment at 35-40 Hz of frequency and 5 g of magnitude [34]. These results seems to suggest that this intervention may have an anabolic effect on bone tissue. In contrast, the modest physical activity at low impact doesn't have any effect on BMD of postmenopausal woman [11]. Aim of this study is to verify the effects of whole body vibration associated to exercise training at low impact, on bone tissue of osteoporotic women underwent to 4 months of low-frequency vibration exercise on a vibrating platform. For ethical reasons connected not only to the experimental nature of this study but also to the short time of treatment, it was used the Quantitative Ultrasound that represent a feasible, sensitive and non-invasive method for

assessing bone tissue, over others methods that use radioactive sources or ionizing radiations [35, 36, 37, 38].

Methods

To evaluate the effects of whole body vibration on bone loss condition, twenty-six osteoporotic women (T-score -3.67 ± 1.10 , Age 63 ± 8.6 years, Weight 66.12 ± 10.7 kg, Height, 161.7 ± 5.9 cm) voluntarily participated in the study and were randomly divided in two groups: experimental (E) and control (C). Table 1 presents physical characteristics of the subjects of both groups. All subjects participating at this study aren't submitted to any pharmacological therapy.

The subjects of both groups participated at the same exercise training program (one hour three times per week) consisted in walking (15 min), flexibility and joint mobility exercises (15 min), free body exercises (15 min.), low impact step exercise (10 min.) cool down exercise (5 min.).

In addition, the subjects of experimental group performed the vibration treatment in the same day before the exercise training program.

The subjects of experimental group were instructed on the outcomes and the potential benefits associated with their participation in the study. Each subject was familiarised with the experimental protocol and signed an informed participation consent, approved by the Ethical Committee of the Italian Society of Sport Science. Subjects under specific traditional treatment for osteoporosis with previous history of fractures or bone injuries were excluded from the study. They underwent to the experimental treatment consisting of whole body vertical sinusoidal vibration delivered through a specially designed vibrating plate

(Nemes LB, Ergotest Europe, Italy). The magnitude of vibration was 5 g ($1g = 9.81 \text{ m}\cdot\text{s}^{-2}$) and the frequency was 30Hz. The subjects exercised three times per week for a total period of three months. The treatment protocol has been previously described [39]. The total vibration exposure was ten minutes per session. The subjects were standing with both legs in semi-squat position (knees bent at 100°) and were allowed to hold a standing stationary metal bar to maintain equilibrium during the exposure to vibration (Figure1). To obtain a complete whole body vibration, the mechanical waves, generated by vibrating plate, were also transmitted to the hands through the metal bar connected to it. During the time-course of the experiment, none of the subjects in the experimental group reported any discomfort from the treatment and only one subject of this group, after the first week of vibration treatment, drop-out from this experiment without appreciable reason. The Compliance of each subject participant to this study, calculated as the number of days attended divided by the 48 days in for months trial (3 days per week for 16 weeks) [40] was about 88%, without statistical difference between both groups.

Quantitative Ultrasonogrammetry (QUS)

Quantitative ultrasound (QUS) measurements were performed before and after the three months treatment period in the proximal phalange of digit II and IV of the dominant arm, using a DBM Sonic 1200 (Igea, Italy) ultrasound device. Two probes are applied to the lateral surface of the fingers, one acting as generator of signal (US frequency = 1.5 MHz) and the other as receiver. The coupling of them with the skin is mediated by a water-based gel. The velocity at which the US traverses the phalanges, in a lateral-medial direction, was

calculated by rate between the distance separating the probes, directly measured by the calliper, and the time elapsing from the emission of the US signal to its reception and expressed in m/s. The device measures the time when the electrical signal, generated by reaches an amplitude of 2 mV at the receiving probe, thus the QUS parameter calculated is the Amplitude-Dependent Speed of Sound (AD-SoS,) for each four fingers and its average value. The AD-SoS has been shown reflecting the mass and the elasticity of bone [36]. The phalanges reflect the largest variations of BMD over lifetime in women [41]. The decreasing of AD-SoS is correlated with decreasing of BMD and loss of trabecular structures, typical conditions of elderly women [42, 43].

Among the other parameters analysed by the device, in the present study, in addition to the average values of AD-SoS and the Ultrasound Bone Profile Index (UBPI) also the T-score will be considered..

The UPBI is an optimum logistic multivariate model, derived from different parameters, for fracture discrimination. It expresses the probability that the subject has a vertebral fracture at the time of QUS evaluation [44].

The T-score was calculated using the AD-SoS measurements. The individual values of QUS were then converted to a T-score according to the following formula:

$$\text{T-score} = (\text{measured values} - \text{average values in young adult}) / \text{SD in young adult}$$

The device has been calibrated by manufacturer using a composite mother phantom and weekly calibrations are performed to control the ultrasound velocity in a Plexiglas phantom. All the QUS measurements were performed by the same operator. The intraoperator reproducibility was already scientifically

documented [45] and the Coefficient of Variation ($SD*100/$ Mean of measurements) of repeated examinations was 0.15% for AD-SoS parameter, calculating on repeated measurements effectuated in the same day on the second finger of a subject 30 times. In vivo short term reproducibility was also assessed by measuring 5 times 7 subjects, randomly selected from both groups, at an interval time not exceeding 7 days; the CV% was 0.75. All the measurements effectuated in this study were performed blind, because the operator didn't know the belonging of patients at the experimental or control group.

Statistical analysis

The data were analysed using the statistical software for the Social Science (SPSS Inc.). A paired Student's t-test was used when comparing longitudinal data within the each group of women. The p values resulting from this calculations are two sided and the minimum level of p value to be considered as significant is 0.05. The data referred to the subject's characteristics are expressed as mean + standard deviation.

Results

As expected, the evaluation of the control group (trained subjects only) showed mainly no changes over the QUS parameters in four months time (table 4). In detail, only five subjects showed slight improvements (table 3). On the other side, the experimental group (vibrated and trained subjects) showed remarkable improvements on the AD-SoS QUS parameter ($p = 0,002$), on the UPBI ($p = 0,01$) and on the T-score ($p = 0,002$) (table 4) except only one subject (table 2).

Discussion

The magnitude of musculo-skeletal interactions is of paramount importance for the maintenance of bone integrity. Physical activity performed early in life has been shown to contribute to high peak bone mass [46]. The results of this study confirm the scientific evidence that some forms of exercise, in particular the ones producing high impact forces, seem to be able to reduce or reverse the age-related loss of bone [47], whereas low impact exercise regimen doesn't have effects on remodelling bone tissue [11]. In effect, a lack of weight bearing activity could favour the likeliness of sarcopenia [48] reducing in this way signals critical to the maintenance of bone mass [26]. Vibration represents a strong stimulus for musculoskeletal structures due to the need to quickly modulate muscle stiffness to accommodate the vibratory waves [39]. Our results suggest that vibrations transmitted to the body by means of vibrating plates may be an effective alternative countermeasure to bone loss. This hypothesis is strongly supported by the effects of such treatment on human skeletal muscles. Vibration has been in fact shown to produce remarkable enhancement in strength and power production following acute [22, 23] and chronic treatments [49]. The extent of the response observed in our experiment (increase in QUS T-score by 57%) is surprising. However, it is our opinion that high magnitude (5 g), frequency (30 Hz) and time of exposure (10 min) of vibration treatment could be assimilated to an high impact mechanical stimulus like that experienced during contact time (~ 200 mms) (references) in ballistic movements (drop jump or high jump, high velocity run), enough to influence the bone tissue remodelling [21, 22, 23]. Moreover, also some influence from hormones could have determined such a remarkable adaptation to vibration

treatment considering that the total exposure time to vibration was relatively short (~360 minutes). Vibration has been in fact shown to acutely increase testosterone and growth hormone levels in healthy individuals [23] following the same protocol used in the current experiment. Taking into consideration the results of these preliminary studies it would not seem far-fetched, then, to suggest that the combination of high-frequency mechanical stimuli and hormonal responses provided by vibration could represent an anabolic signal to musculo-skeletal tissues. The higher improvement obtained in these study, respect to the results present in scientific literature, could be due to different factors. One of these, associated to the overestimation of QUS measurement, following our opinion, could regards the effects of incommensurable vibration transmitted by metal bar to the hand directly, determining a local effect that could not completely representative of proper skeletal specific sites of the QUS measure. However, the present findings demonstrate, the effectiveness of high impact stimulus of vibration exercise on bone tissue and provide support for its use as a non-pharmacological intervention to prevent and/or reverse bone loss in humans.

These preliminary studies are promising, longer term, larger population scale studies must be performed in order to verify the effectiveness of vibration treatments and its combination with exercise regimen on the spine and the lower limbs for to prevent bone loss falls and related bone fractures.

FIGURES AND TABLES

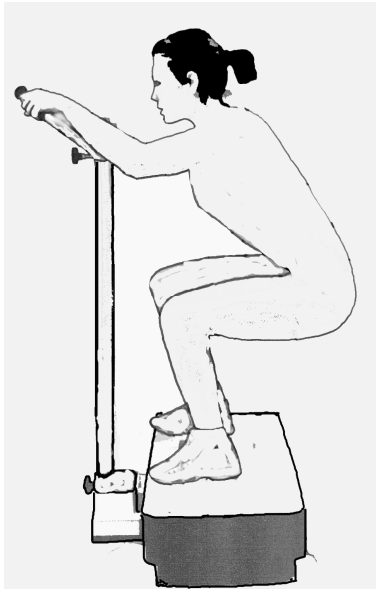


Figure 1. Position assumed by subjects of Experimental Group on vibrating plate (Nemes)

Variables	Control Group		Experimental Group	
	Mean	SD	Mean	SD
Age (years)	61.2	7.3	64.8	5.6
Height (cm)	161.6	4.4	173.1	10.6
Weight(kg)	68.6	11.2	68.0	11.9

Table 1: Descriptive data (mean \pm SD) of the subjects of both groups

Exp Group	T-Score		AD-SoS		UPBI	
	pre	post	pre	post	pre	post
subject 1	-2,46	-2,39	1952	1957	0,39	0,38
subject 2	-2,49	-0,16	1950	2113	0,57	0,84
subject 3	-5,24	-2,04	1757	1981	0,18	0,34
subject 4	-3,04	-2,63	1911	1940	0,49	0,57
subject 5	-2,33	-1,37	1961	2028	0,36	0,45
subject 6	-3,86	-1,24	1854	2037	0,26	0,74
subject 7	-3,41	-3,54	1885	1876	0,29	0,26
subject 8	-4,53	-1,31	1807	2032	0,23	0,7
subject 9	-3,93	-3,31	1849	1892	0,27	0,24
subject 10	-2,77	-2,46	1930	1952	0,32	0,4
subject 11	-5,59	-4,11	1733	1836	0,25	0,22
subject 12	-2,41	-1,63	1955	2010	0,41	0,45

Table 2. QUS parameters for individual subjects, at the beginning and four months after the vibration treatment. The treatment was effective in all except one of the subjects of the Experimental Group.

Control Group	T-Score		AD-SoS		UPBI	
	pre	post	pre	post	pre	post
subject 1	-2,43	-2,74	1954	1932	0,63	0,58
subject 2	-3,63	-4,39	1870	1817	0,28	0,22
subject 3	-3,83	-3,96	1856	1847	0,21	0,22
subject 4	-3,41	-3,80	1885	1858	0,35	0,23
subject 5	-3,61	-4,11	1871	1836	0,35	0,27
subject 6	-5,23	-5,91	1758	1710	0,18	0,11
subject 7	-2,29	-2,06	1964	1980	0,38	0,39
subject 8	-4,20	-4,16	1830	1833	0,21	0,21
subject 9	-3,60	-3,51	1872	1878	0,20	0,20
subject 10	-5,64	-5,77	1729	1720	0,13	0,21
subject 11	-3,51	-3,44	1878	1883	0,26	0,31
subject 12	-3,83	-3,96	1856	1847	0,21	0,22
subject 13	-2,76	-2,20	1931	1970	0,40	0,48

Table 3. QUS parameters for individual subjects, at the beginning and four months of control group. Only five subjects showed slight benefit of exercise treatment.

QUS Variables	Control Group			Experimental Group		
	Pre	Post	T-test (p) =	Pre-treatment	Post-treatment	T-test (p) =
T-Score	-3,69 (0,96)	-3,85 (1,15)	n.s.	-3,50 (1,13)	-2,18 (1,12)	0,002
AD-SoS (m/s)	1865,69 (67,13)	1854,69 (80,50)	n.s.	1878,67(79,45)	1971,17 (78,69)	0,002
UPBI	0,29 (0,13)	0,28 (0,13)	n.s.	0,34 (0,11)	0,47 (0,21)	0,01

Table 4: Mean values \pm SD of AD-SoS and UPBI before (Pre) and after (Post) three months in Experimental Group treated with Whole Body Vibration and in Control Group. Statistical differences in either groups were analysed using Student's t-test for paired observation.

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STUDY II

Isoinertial-sEMG and Vibration sEMG test assessment in ACL Reconstruction

Purpose. Reparative knee joint surgery is usually followed, in a high percent of patients, by a long period of weakness of leg extensor muscles. Most of the muscular evaluation assessments have been performed with constant speed dynamometers where the maximal speed allowed by the isokinetic apparatus is however lower than 25% of the maximal speed achieved during natural leg extension. The aim of the present research is to introduce a new procedure to determine the amount of functional recovery after knee joint surgery. We propose to compare the biomechanical performance in the leg extensor test synchronised with sEMG, and the response in the EMG activity to vibratory stimuli, in the operated and in the uninjured legs.

Methods. Ten patients with unilateral knee joint operation, with implantation of semitendinous muscle portion, were recruited from the day hospital of rehabilitation department of Tor Vergata University Hospital. The follow-up from the surgery intervention was averagely 3,5 months and all patients were submitted to the same rehabilitation therapy.

Results. During leg extension test of the mechanical velocity ($p < 0,002$), the displacement ($p < 0,004$) was lower and the sEMG activity of vastus lateralis and medialis ($p < 0,003$) was higher than the non-operated leg. The EMG activity monitored during vibration treatment was much higher in the operated compared to controlateral one ($p < 0,02$).

Conclusions. The assessment of biomechanical parameters associated to sEMG activity in isoinertial dynamic and vibration test, represented by the comparison of operated/non-operated, showed to be an effectiveness clinical method of assessment the neuromuscular behaviour of the operated limb in different exercise regimens. Results of our study suggest that combination of isoinertial

dynamic performed in different and functional way and vibration stimulation either associated to sEMG recordings may allow for detection of impairment of neuromuscular functionality system as well as monitoring progress of the rehabilitation programs.

Introduction

Reparative knee joint surgery is usually followed, in a high percent of patients, by a long period of weakness of leg extensor muscles (11, 26). It is likely that the strength modulation is the result of many factors such as increased pain sensitivity, the reduction in peripheral receptor input and the effects of disuse and immobility of the muscle tissue. Most rehabilitation programs, after knee surgery, usually involve isokinetic training, and most of the muscular evaluation assessments have been performed with constant speed dynamometers, even though such systems exhibit some limitations (1, 24, 27). The maximal speed allowed by the isokinetic apparatus is however lower than 25% of the maximal speed achieved during natural leg extension (8). Consequently, patients were asked to develop a remarkably high muscle strength; however, a high level of muscle tension is strongly influenced by the patient's pain threshold. Therefore, functional dynamic tests requiring very low muscular strength should be used more often in injury rehabilitation of the lower extremities. Pfeifer and Banzer (23) have reported that different test conditions (stair descending, one-legged drop jump, one-legged cyclic hops) reveal different and persisting changes of the motor performance that cannot be detected by kinematics parameters alone. However, the assessment of neuromuscular function is far from sufficient for covering the large spectrum of biological changes, which occur with injures and after surgery. In this respect, a new technique consisting of monitoring the electromyographic activity of the leg muscles during a whole body vibration treatment is suggested. This method

allows the possibility to detect and quantify proprioceptor function and altered neural strategy of motor pool recruitment after injury or surgery.

Therefore, the aim of the present investigation was to evaluate and quantify the magnitude of muscular power and EMG activity developed during voluntary movement and proprioceptor functions induced by mechanical perturbation caused by vibration, following knee surgery. This procedure consist of two different tests; 1) the leg extension test measuring muscle power and monitor EMG recordings and 2) the EMG response to vertical sinusoidal whole body vibration (WBV).

Method

A group of ten male and female subjects (age $26.1 \pm 3,9$ yrs; weight 74.9 ± 10.8 kg; height 173.4 ± 10.2 cm) who previously underwent unilateral operation of Anterior Cruciate Ligament (ACL) volunteered to participate in this study. The Ethics Committee of the Italian Society for Movement Science approved the study and all subjects signed a written consent form before they were subjected to any testing. Patients were postoperatively tested from 12 weeks after surgery. The schedule consisted of three consecutive phases: 1) a period a warming up and stretching; 2) five trials of maximal leg extension; 3) two trials of 10 s training on the vertical sinusoidal whole body vibration (WBV).

Testing procedures

The testing session started with the anthropometric measurements of height and body weight followed by 10 min of warm up. The latter consisted of

10 min cycle ergometer pedalling at a speed of $21 \text{ km}^{-1} \cdot \text{h}^{-1}$ and at 50 watts (W) followed by 5 min stretching of the quadriceps and the triceps surae muscles.

Leg extension assessment for mechanical power calculation

All subjects, previously accustomed to exercises, performed a maximal dynamic leg extension exercise free load. The weight of the calf and the foot represent resistance of approximately 5% of the individual body weight and needed to be overcome by all patients. For each leg, five attempts were performed at 1 min inter trial interval. Since 2 or 3 trials were needed to reach a performance plateau, the last 2 trials of each set of measurements recorded (trial 4 and trial 5) were used for calculation of test re-test reliability (4, 26) while best individual performance was used for statistical analysis. During the leg extension movement the displacement of the lower limb was monitored with a sensor (encoder) machine (Muscle Lab- Ergotest Technology A. S. Langensund, Norway), interfaced with a PC. When a subject moved a foot, a signal was transmitted by the sensor every 3 mm of foot displacement. From the obtained data, it was possible to calculate several variables, i.e., average velocity, acceleration, average force (F), and average power (P), corresponding to the load displacements (for details see ref. 4). However, it has been shown that the P is the most sensitive variable among all the mechanical variables studied, therefore, only the P was considered for statistical analysis (4).

EMG analysis

The electrical activity from the vastus lateralis and vastus medialis muscles of each leg was recorded during the leg extension movements by bipolar surface electrodes (inter-electrode distance 1.2cm) fixed longitudinally over the muscle belly and amplified (gain 600, input impedance 2 Giga-ohm, CMMR 100dB, band-pass filter 6-1500 Hz). The EMG raw signal was converted to a DC signal through the MuscleLab built in RMS converter (frequency response 450 kHz, averaging constant 100ms, total error $\pm 0.5\%$). The resulting DC signal, representing the average power of the raw EMG signal during the past 100ms, was then sampled at 100Hz simultaneously with other related biomechanical parameters. The EMG was expressed as a function of time (μV).

The subjects wore a skin suit to prevent the EMG cables from swinging and to reduce or eliminate any movement artefact. The EMG values of both vastus lateralis and vastus medialis muscles were averaged for statistical analysis, as suggested earlier (7, 28). The values of trial 1 and trial 2 were also averaged for statistical analysis.

Whole body vibration treatment procedure

Immediately after the leg extension assessment, all subjects were exposed to vertical sinusoidal whole body vibration (WBV) using the NEMES L-X (Boscosystem, Rieti, Italy) device as follows: vibration frequency = 35 Hz; vertical displacement = ± 4.0 mm; acceleration = 51.5 m.s^{-2} ; training duration: 10s; number of trials = 2; inter trial interval = 120s. The vibratory stimuli were applied while the subjects were in standing position with the toes on the

vibration platform; the knee angle was pre-set at a flexion of 100°. The EMG activity was recorded from both vastus lateralis and vastus medialis muscles from the same place and with the same gain and amplification as during leg extension and in absence and in presence of vibratory stimuli.

Statistics

Standard statistical methods were employed, including mean + SD. The Pearson Product Moment Correlation Coefficient (r) was used for test re-test measurement reliability. The CV of test re-test measurements was calculated using the following equation (25):

$$CV = \frac{(200 \bullet SD) \bullet (x^1 + x^2)^{-1}}{\sqrt{2}}$$

Where x^1 and x^2 are the mean values of two successive measurements and $\pm SD$ is the standard deviation of the mean difference between test re-test measurements. Univariate and multivariate paired comparisons procedure with suitably defined contrasts; Wilcoxon and Friedman's non-parametric tests were also used. The level of statistical significance was set at $P < 0.05$.

Results

During the leg extension test, the mechanical velocity of the operated leg showed a significantly lower value ($P < 0.002$) than the controlateral leg (Table 1), as in mechanical parameters but not in the EMG activity that was recorded simultaneously. The EMG activity recorded during the WBV treatment was significantly higher ($P < 0.001$) in the operated compared to non-operated leg

(Table 2, Fig.1). The greater response in the operated side occurred at the beginning of the vibratory stimuli and lasted throughout the entire time of stimulation (Figure 2). During WBV the operated limb demonstrated larger values ($P<0.01$) than the controlateral non-operated one (Figure 2).

Discussion

The results of our investigation suggest that during recovery from a knee joint surgery, a decreased muscular power during voluntary effort, in the operated leg was associated with an increase in EMG response to total body vibration.

Before discussing this finding, it is important to address a few methodological issues. Our patients were familiar and accustomed with the leg extensor apparatus before the start of testing sessions. Moreover, in each patient the test re-test reliability showed an acceptable consistency in their performance with no signs of fatigue. Although, closed kinetic chain evaluation test have been promoted as more functionally appropriate and safer than open kinetic chain tests (1, 24, 27). With iso-inertial dynamometer used in the present study, it was possible to safely measure in the postoperative conditions the functions of muscular behavior during open chain performance. The leg extensor method allowed the use a very low external resistance, avoiding the development of high muscle tension, which for a post surgery patient represent a limitation of the neuromuscular behavior, since pain threshold sensibility may interfere with the voluntary effort. The leg extensor test was performed before the WBV and it has been reported that 10 min WBV was able to increase

muscle force, power and movement velocity (5), while repeated trials of WBV for 60 seconds were able to increase plasma concentrations of both testosterone and growth hormone (6). To prevent possible effects in the EMG response in the second WBV trial, vibratory stimuli were conducted for only 10s, and separated by two minutes inter-trial interval.

The EMG activation by WBV was similar to that obtained by the tonic vibration reflex, a response elicited by mechanical vibration (10-200 Hz) applied to a single muscle belly or to a tendon (19). In the tonic vibration reflex the motor neuron excitation has been mainly attributed to activation of primary endings of muscle spindle receptors, although the amplitude and the frequency used are able to excite also other muscles, joints, tendons and ligament receptors (14, 15, 18). Receptor activation may be related not only to direct effects of the mechanical stimuli but also, indirectly, to the muscle contraction that follows the motor neuron reflex excitation (16). There is no doubt that both, the lesion that has preceded the operation, and the operation itself with the accompanying inflammatory reactions might have transiently affected the function of joint and ligament receptors.

During WBV the mechanical stimuli most likely elicit simultaneous and diffuse activation of spindle receptors innervating both agonistic and antagonist muscles acting on the same joint as well as vestibular receptors. The present experiments are not adequate to provide the mechanisms of the reduced mechanical power and of the increased EMG response to WBV in the operated leg but they clearly indicate that there are sharp changes in both tests mainly in the early weeks after knee surgery. Besides muscle spindles, the role and the

function of joint and ligament receptors on proprioception and functional joint stability is highly debated. After knee joint surgery, either enhancement of the threshold for detection of passive motion (2, 13) and a reduced ability to actively reproduce a guided knee joint position in the ACL operated side with respect to healthy side (3) or no difference between the two limbs (9) has been reported. These different results might be due to the differences in reconstruction surgery and/or due to different types of rehabilitation programs. Our patients had been submitted to different types of knee joint surgery and to different rehabilitation programs and therefore their response to the WBV is more likely related to general mechanisms of adaptation such as response to pain, inflammation and immobility.

The EMG activity deserves additional and further discussion. While in the operated side during the leg extensor test the mechanical power was lower than that in the controlateral side, no difference in the EMG activity of both sides was recorded. On the contrary, in response to vibratory stimuli the EMG activity was much higher in the operated side than in the non-operated one and only in the muscles acting in the proximal side of the knee joint: no differences between the two sides were recorded in the EMG activity in the distal part (mm. medial and lateral gastrocnemius). We are aware that surface EMG electrodes do not provide an exact recording of the underlying muscle fibers electrical activity. More in general, since the EMG activity is the expression of motor neuron activity, it seems that, in a condition in which the strength of muscle fibers is decreased, the motor neuron activity is not modified in response to a central command for a maximal dynamic effort such as, the leg extension test

but is greatly increased in response to a peripheral stimulus, such as the mechanical vibration.

The increased response could be due to a selectively modified response of the motor neuron to the peripheral input and/or to an increased excitability of the muscle spindles to the mechanical stimuli. The latter hypothesis is not supported by animal experiments (21) that have shown that after long lasting limb immobilization of a healthy muscle at a short length there is a reduction in mean fiber area in all fiber types and a reduction in peak tetanic force. The reduction in peak force was greater than expected because of fiber atrophy in slower fiber units. As for muscle spindles and tendon organs, their responses in immobilized muscles reflected atrophy changes in extrafusal fibers with no substantial disturbance in receptor function. As for the first hypothesis, there is evidence that following training there are chronic adaptations in short and long latency stretch reflex responses, which facilitate greater force production for sport activities and quicker reaction times to unforeseen perturbations to planned movements (17). In particular Wolpaw (30) has developed a model in which primates can be trained to increase or decrease the amplitude of the spinal stretch reflex or H-reflex under conditions of a food reward and similar results have been reported in humans (12). As for the present results, taking into account also other plastic changes, which occur following training (10, 20, 22, 29). It may be suggested that the increased response to WBV in the quadriceps muscle of the surgically operated knee, could represent the expression of adaptation mechanisms in the central nervous system to partial immobility and to reduced force in the corresponding muscle. In a motor neuron that is poorly

involved in motor commands and therefore producing a reduced number of muscle contractions and stretches, the development of an increased responsiveness to muscle stretch in afferents represents a plastic mechanism that is able to improve the efficacy of the gamma loop during movement. Any peripheral or central stimulus, which excites fusi-motor neurons becomes particularly effective to increase the firing of the skeleto-motor neurons and therefore increases muscle strength. It is interesting to underline that this adaptive mechanism is reversible since it may subside when the muscle recovers the original strength.

Conclusion

The aim of the present study was to propose and assess new procedure to detect the impairment and the progress of a rehabilitation program. The leg extensor test displays a high reproducibility, uses very low external resistance and therefore may provide quantitative evaluation of muscle capacities a few weeks after surgery. A substantial limitation could be related to the subject motivation to perform a maximal contraction of an injured leg. The EMG response to WBV has the advantage to record diffused muscle activation in which it is possible to compare contemporaneously the injured and the healthy leg reflex response to the same stimulus. The coupling of the two tests, we believe, offers the opportunity to assess the degree of recovery during a rehabilitation program and/or of a persistent deficit.

TABLES AND FIGURES

		PEAK VEL (m/s)	AV VEL (m/s)	Displ (cm)	EMGs (mV)
Operated leg	AV±SD	2.77±0.46	1.47±0.22	45.47±8.98	0.03±0.002
Non operated leg	AV±SD	3.95±0.93	2.07±0.43	59.5±10.68	0.05±0.004
T-test OL/NOL	p <	0.0011	0.0025	0.0038	0.0314

Table 1. The mechanical parameters and sEMG of operated and non operated legs developed during leg extension performance.

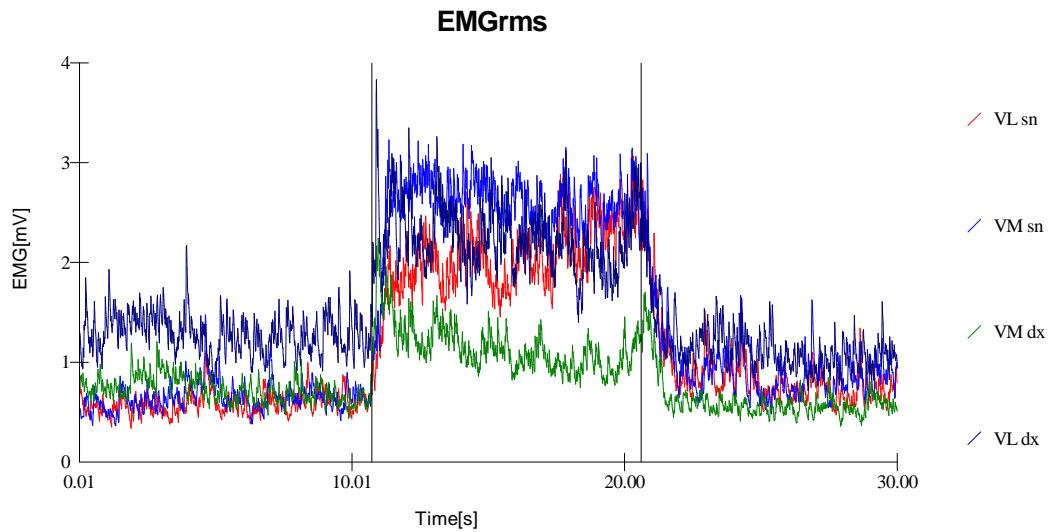


Fig.1. Electromyographic activity (EMG) recorded from leg extensor muscles of a operated subject (mm. vastus lateralis: VLsn and VLdx and medialis: VMsn and VMdx of both left and right legs), before and during vibration treatment. During the administration of vibration, higher EMG activity was noted in both legs. However a remarkable enhancement of the EMG was noted in the postoperated leg (VLsn and VMsn), compared to healthy one.

		EMGs Quadric. (mV)
Operated leg	AV±SD	116.42%±0.62
Non operated leg	AV±SD	58.62%±0.38
T-test OL/NOL	p <	0.002

Tab2 . The EMG detected in the leg extensor muscles during WBV treatment is presented as a percentage of the baseline (100%). Statistical significant differences between mean ratios of non operated and operated is shown. (**p<0.001).

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5. CONCLUSION

The structural integrity of a biological system is maintained if it is systematically underwent to the same environmental stimuli that contributed to the morphological and functional ontogenetic evolution. Mechanical stimuli under functional threshold of magnitude, frequency and intensity, associated to biological conditions modified by hormonal perturbations specifics on pre-post menopause phases, causes a functional remodelling of bone tissue characterised by the resorption process. Hormonal therapies and nutritional supplementations, alones, aren't enough to reduce bone loss. The only means, capable to counteract this degeneration process is the functional mechanical stimulus, represented by physical exercise. In this contest the vibration energy represent a safe and healthy training method, effectiveness for its easy application in terms of time treatment and operability. This thesis show that low frequency, high magnitude are enough to prime the bone's anabolic process in four months only.

Moreover, the response of neuromuscular system to vibration, analysed trough the use of sEMG, is an important assessment method. Associated to isoinertial test integrated with sEMG, actually is the only system capable to give information on neuromuscular strategies in post-operated subject, as for monitoring the rehabilitation program, as for predicting neuromuscular abnormalities in prevention possible injuries that for defined the right time to return to physical activity, overall for high level agonistic athletes.