THE APPLICATION OF VIBRATIONS ON THE HUMAN BODY

Scientific information

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INTRODUCTION

Everything in the universe vibrates. The human being is also affected by this reality, which manifests itself outside and inside him. Vibration is a life force. As far as man is concerned, vibration should be divided into two fundamental areas: beneficial vibration and harmful vibration.

In the infinite range of vibrations, human perception is placed in a band that goes from the Esteroception, through the frequencies of sensoriality (the five senses), to Proprioception, through the resonance frequencies of our own cells and organs. The stresses of life and the vibrations resulting from them have a tangible influence on the state of well-being and health. Negative stresses include, for example, stress (introception) and noise (exteroception).

The value of vibration therapy has been known since ancient times. It has been applied through sounds, the tapping of objects on the body and visual effects through colours.

In the last decade, science has succeeded in giving mechanical vibration a therapeutic face through research, with great positive results for human health. Mechanical vibration has opened the door to true global therapy for the human being.

Chapter 1

WHAT IS VIBRATION

The term 'vibration' describes an oscillatory-type movement around a reference position at regular intervals.

The number of complete cycles completed per unit of time, i.e. per second, is called frequency. Frequency is measured in Hertz (Hz). Hertz defines how many oscillations (vibrations) occur in one second. What concerns us is mechanical vibration.

The expression 'mechanical vibration' refers in particular to a mechanical oscillation around a point of equilibrium. It should also be clearly stated that recently introduced terms such as **'vibrational energy' have no scientific meaning.**

Oscillation is the movement that a moving point makes in order to move away from and return to its starting position: in fact, we often speak of small motions around the equilibrium position. Oscillatory motion can occur periodically or alternately.

If we observe an object during vibratory motion (figure above), we can observe periodic movements; the time between two passages of a point through the reference position (equilibrium or starting position) is called the period (or cycle) [s].

The magnitude of the oscillations is called amplitude. The number of oscillations per unit of time is the frequency.

Every day, the human body is subjected, consciously or unconsciously, to vibrations of different types, from those produced by a car or train to those generated by a car or train. from industrial machines or tools such as pneumatic hammers, drills, etc.

Low-, medium- and high-frequency vibrations can have both positive and negative effects on the body. Exposure to vibrations can have serious repercussions for the body.

on the human body, depending on the type of oscillation and the duration of exposure to which the body is subjected. **The fundamental factors are the amplitude of the contact surface with the vibrating object, the frequency of the vibration, the amplitude (transmitted wave power), the exposure time and the direction of propagation of the vibration.**

The negative effects are related to the energy waves transferred from the vibrating source to the exposed body, which cause various effects on tissues and organs before they are attenuated.

The human body, like any other machine, can only tolerate certain energy levels (shock waves) of vibration, beyond which, as a consequence, it begins to deteriorate and suffer long-term damage.

The human body does not vibrate as a single mass with a natural frequency, but the organs and each individual segment of the human body have their own resonance frequency. This causes each area of the body to amplify or attenuate the input vibrations according to its own resonance frequency.

The propagation of sounds and noises transmits energy in the form of pressure waves in the air: in the case of vibrations, energy appears in the form of waves propagating in a solid structure. A body vibrates when it describes an oscillatory movement around a position of static equilibrium.

Exposure of the hand-arm system to vibrations, for example, is associated with an increased risk of vascular, neurological and musculoskeletal injuries to the hand-arm system (e.g., pneumatic hammer).

Chapter 2

NEUROPHYSIOLOGY OF VIBRATORY PERCEPTION: RECEPTORS IN THE HUMAN BODY

Vibratory perception is in fact a mechanical type of sensitivity and, for this reason, involves receptor structures that are sensitive to mechanical stimuli, i.e. mechanoreceptors (Mouncastle and Rose, 1959 [1]). **The mechanoreceptors are microstructures with various functions that receive vibratory signals from different parts of the body**.

From an anatomical-structural point of view, the mechanoreceptors have both myelinated fibres of different calibre and amyelinated fibres, and are found in different types **of** tissue, such as **skin, muscle tissue, periosteum, capsules and joint ligaments**. Specifically, **the muscle mechanoreceptors take part in the reflex response phenomena following the stretching of the muscle-tendon unit**.

These types of mechanoreceptors constitute highly specialised structures and are referred to as the "anulo-spiral endings" of the neuromuscular spindles. From a functional point of view they are connected to myelinated fibres belonging to Lloyd's group Ia; the latter show a high conduction velocity of around 100 m/s-1 and respond selectively to vibratory stimuli with frequencies from 90 to 150 Hz (Hagbarth, 1973 [2]).

In addition, **four** other **types of mechanoreceptors can be identified in the** human **skin** by means of microneurographic techniques, which can be classified according to the adaptation and size of the receptor field (Johansson and Valbo, 1983 [3]). However, **not all of the four types of receptors identified are sensitive to vibratory perception**, and even those that are receptive to the vibratory stimulus show **differences in the response dictated by the frequency of the vibratory stimulus itself** (Mountcastle et al., 1969 [4]).

Mountcastle et al. (1969), following animal studies, classified the receptor units responsible for the **sensory reception of the tremor-vibration stimulus** into three classes, which are distinguished according to the type of nerve ending, the area of the receptor field of action, the adaptive properties and the dynamic sensitivity.

The three classes of mechanoreceptors thus identified are:

- **Fast-adapting mechanoreceptors** are sensitive to movement. They are essentially found in **the dermis** and correspond to **Meissner corpuscles**, otherwise known as FA-1 (Fast Adaptation-1).
- The **slow-adapting mechanoreceptors**, also **located in the dermis**, correspond to **Merkel's discs** or SA-1 (Slow Adaptation-1). They show receptivity both to movement and to the intensity of the mechanical stimulus to which they are subjected.
- **Pacini corpuscles** or FA-2 (Fast Adaptation-2), located **in the subcutaneous tissue.**

Studies conducted by Cosh [5] (1953), on the vibratory perception threshold, before and after skin anaesthesia, showed that the receptor threshold for vibratory sensitivity **is** located **subcutaneously**. For this reason, **the Pacini corpuscles** can be considered to all effects **as the mechanoreceptors most involved in vibratory perception**. To confirm this hypothesis, it should be noted that in the elderly individual there is an elevation of the threshold of vibratory perception concomitant with a loss of the Pacini corpuscles (Cauna and Mannan, 1958 [6]).

With regard to the mechanoreceptors located **in the dermis**, those that play the **most important role in vibratory perception** are **the Meissner corpuscles**, which, however, show a selective type of activation for **low frequency vibratory** stimuli**,** between **5 and 40 Hz** (La Motte and Mountcastle, 1975 [7]). In this regard, it should be recalled that the **psychophysical sensation at the liminal level perceives low frequency vibrations, around a value of 40 Hz, as a sensation of tremor,** otherwise defined with the term **"flutter"** (Talbot et al., 1969 [8]). **On the** contrary, **for higher frequency vibrations**, of the order of about **100 Hz,** a **real sense of vibration** is perceived. For this reason, the perception of the **flutter** effect can reasonably be attributed to Meissner corpuscles, whose optimal reception is in the range between 5 and 40 Hz, while the perception of the vibratory stimulus is essentially attributable to Pacini corpuscles, which have an optimal vibratory frequency of around 100 Hz, even though their receptive range is actually between 90 and 600 Hz (Loewenstein and Skalak, 1966 [9]).

Chapter 3 CLASSIFICATION OF VIBRATIONS

Vibrations can be classified according to several parameters.

In addition to frequency, vibrations are also characterised by other, albeit less decisive, closely related parameters, such as amplitude, speed and acceleration.

Acceleration is an important parameter for assessing the body's response to vibration, as humans feel the variation of a stimulus more than its duration.

In order to obtain the maximum beneficial effect, it is necessary to consider the duration of exposure, the area in which the vibration is administered, the resonance frequency emitted, the ergonomic factor (the posture), the psychological condition and environmental factors.

It is therefore necessary to consider the point of application of the vibration. For this reason, vibrations can be divided into:

- vibrations transmitted from a single source to the whole body;
- vibrations with multiple sources and involving the whole body.

3.1 DIFFERENCE BETWEEN ELECTROSTIMULATION AND VIBRATION

Electrostimulation seems to be beneficial in the post-traumatic period, in the post-operative period or as a massage to reactivate the initial function or for the use of analgesic currents such as TENS.

We are not talking about benefits related to performance and proper biomechanical function.

Unlike vibration, the muscular response of electrical stimulation is circumscribed. Furthermore, it does not involve stimulation of the proprioceptive systems present in muscles, tendons and joints, as electrical stimulation does not, like mechanical stimulation, exert effects on Pacini and Meissner mechanoreceptors.

While mechanical vibration activates the entire muscular system through the the proprioceptive system, the electrostimulator obtains only the contraction of the agonist muscles, with the consequent absence of stimulation of the proprioceptive system to the detriment of the important functions of intermuscular coordination.

Chapter 4

MECHANICAL VIBRATION AS A FORM OF PROPRIOCEPTIVE STIMULATION

The Russian physiologist Pavlov demonstrated in 1927 that the appropriate association of two suitable stimuli could modify some motor and/or behavioural functions in cats (paradigms of associative neuronal conditioning, for the temporal association of two stimuli). Subsequently, this phenomenon was defined at a cellular level and we came to speak of **Long Term Potentiation (LTP), i.e. long-term potentiation (months) of selected nerve networks.**

Every year several hundred scientific publications show a multiplicity of methods for inducing LTP phenomena in neuronal networks. The effects of **associative conditioning are characterised by a persistence of weeks or months as opposed to minutes or hours of conditioning**, a great magnitude of the effects and completely physiological mechanisms, since these procedures can only activate physiological mechanisms. Given this body of work, it appeared possible to induce a **form of LTP in the proprioceptive network, thus rapidly improving muscular performance in the long term, using a very simple and entirely non-invasive procedure**.

In the last 10 years some research groups, belonging to **different university institutes** (*Department of Sciences of the Locomotor Apparatus and School of Sports Medicine University of Rome "La Sapienza", Chair of Physical Medicine and Rehabilitation. Department of Internal Medicine, Section of Human Physiology and Department of Medical and Surgical Specialties, Section of Orthopaedics, University of Perugia, Institute of Human Physiology, Catholic University of Rome, Department of Science and Society, Faculty of Motor Sciences, University of Cassino*) have tried to identify a mechanical vibratory stimulus able firstly not to cause any damage, and secondly to have therapeutic effects **by acting on the proprioceptive control network.**

This has led to the development of research into the use of sequences of mechanical microstimuli, perceived as vibrations by the patient, but actually constituting **a real code that can be read by the central nervous system and that can markedly enhance selected motor functions. It** has been ascertained that this very simple and completely non-invasive procedure **induces a form of LTP in the proprioceptive network, improving quickly and in the long term, muscle performance**.

Very recent work converges on two aspects: in order to have persistent effects, mechanical vibration must last for an adequate time (10-15 minutes). With regard to the increase of the muscle tone of the gravitation muscles, the mechanical vibration must have a frequency[10] to which the proprioceptive circuit system appears particularly sensitive (90-120 hz), and must be administered to relaxed muscles. Furthermore, for skeletal muscle strengthening, in addition to the signal produced by mechanical vibratory stimulation, it is necessary to have the participation of the patient through the contracture of the target muscles. The mechanical stimulus is therefore associated with the simultaneous voluntary contraction of the stimulated muscle: in this way, two simultaneous stimuli arrive on the control network of the muscle, one induced by the patient, the second given by the vibration.

The ideal application is developed in 3 treatments of 10 minutes per day for 3 consecutive days. Each session should be separated by 3 to 10 minutes of muscle relaxation and suspension of the vibratory stimulus (the cycle of 3 sessions can be carried out in a time of
45 minutes per day for 3 consecutive days). The results of this research have been presented at conferences[11].

The unilateral effects on healthy subjects and the rapidity of the effects (24 hours) in orthopaedic patients suggest a direct action of the treatment on the central nervous system. In addition, the recovery of stability on one leg with eyes closed in patients with ACL reconstruction (anterior cruciate ligament) suggests that the **treatment may have modified the analysis of proprioceptive information**. **The persistence of the effects finally suggests the effective induction of plastic modifications of the proprioceptive circuitry**. No side effects have ever been observed.

This is a completely new way of 'reprogramming' (almost a kind of computer 'up grade') **the nerve networks controlling the muscles**. This new frontier of training (in sport, but also in rehabilitation) is based on a fundamental principle: **muscular performance is not due to the muscle mass available, but to how it is managed**.

A macroscopic example is offered by the sprinters: Mennea and his contemporaries had muscle masses more than 50% smaller than today's sprinters, but their times were very hard to beat. They were far more efficient muscle machines than those of today. The reason for this has long been known to neurophysiologists: their nervous systems were able to manage their muscles optimally, their training focused on fluidity of performance in order to achieve maximum efficiency.

Today, unfortunately aided by chemistry, contractile mass is sought for more power, but performance becomes less and less effective.

Since effectiveness therefore depends far more on controlling muscle mass than on its volume, it is essential to increase this function. There are techniques, based on the processing of mechanical vibration signal sequences, to obtain forms of Long Term Potentiation (LTP) on specific nerve functions. With these techniques it is possible to act directly on neuromuscular control with extraordinarily powerful effects (increases of several tens of percentage points), rapid (with applications of a few minutes repeated in short periods) and persistent (weeks or months).

It is remarkable that this new system not only produces impressive effects in terms of size, but is also the antithesis of doping. The latter pushes the subject beyond his possibilities and leads him to spend far more energy than the body is willing to do. On the other hand, strengthening motor control means optimising the athletic gesture, saving energy in each movement, and therefore allowing a greater number of movements with the same energy expenditure.

Improved control allows you to concentrate and express explosive force without increasing **it**: performance is enhanced by better muscle management.

Chapter 5

EVOLUTION IN STUDIES OF MECHANICAL VIBRATIONS APPLIED TO THE HUMAN BODY

Cyclically, the scientific world reawakens interest in possible therapeutic or sporting applications of mechanical vibration, and over the years this research has given rise to an impressive literature.

The first scientific work on the use of vibrations for therapeutic purposes in humans (so-called therapeutic vibratory exercise) **dates back to 1949**, when **Whedon et al**. reported on the **positive effects** of vibrations generated by a special oscillating bed on metabolic abnormalities in bedridden patients in plaster casts.

A subsequent experimental study (Hettinger, **1956**) showed that **vibrations with a frequency of 50 Hz and an acceleration of 10 g were able to increase the area of the muscle section and reduce the fat tissue within the muscle.**

In the purely therapeutic field, almost forty years later, Schiessl (1997) patented the use of a machine capable of generating rotational oscillations, while in the same period Fritton et al. (1997) developed a machine based on translational oscillations (a technique later abandoned due to its poor results). In both cases, the field of application of these devices was to try to obtain a **stimulation of bone growth, thanks to specific frequencies that we could define with the term 'osteogenic'.**

One year later, experimental work by **Flieger et al. (1998) showed that there was an increase in bone proliferation in animals subjected to vibration.**

Since 1994, Prof. C. Rubin has focused his studies on understanding the cellular mechanisms responsible for **bone** growth, **healing and homeostasis and, in** particular, how biophysical stimuli (mechanical and others) mediate these responses12 . The results of his work show that these stimuli induce an **inhibition of osteopenia,** the promotion of bone regrowth in prostheses or skeletal defects, and also a **more rapid healing of bone defects.**
fractures.

However, until 1987, all studies of mechanical vibrations were focused on the effects on the skeletal system, i.e. osteoporosis treatment, trauma recovery, bone decalcification, bone degeneration and decreased calcification in astronauts. It was only at the end of the 1980s that the first studies appeared on the possibility of **increasing the contractile capacities of muscles subjected to vibratory stress** (Nazarov and Spivak, 1987). Since then, research in this specific field has become more and more exhaustive, and the benefits of controlled vibrations began to be analysed from the muscular point of view as well.

Russians Nazarov and Spirav worked for the Russian government and their vibration studies were used to support the astronauts' gymnastic activities in space. In the early 1990s, the Americans could stay in space for no more than 120 days and always had severe muscle and bone problems, while the Russian astronauts managed to break record after record by stationing two astronauts in space on the MIR orbiting station for 450 days.

Since then, research in this specific field has become more detailed, thanks above all to the studies conducted by **Prof. Carmelo Bosco, one of the greatest exponents of the study of the human body's response to mechanical vibrations**. He developed a training method (AV - Allenamento Vibratorio) capable of improving the power, resistance and speed of the subject under examination, by performing simple exercises on a vibrating platform at certain frequencies, also making it possible to treat the elderly and the injured, without having to resort to unpleasant re-education therapies [13].

In 2007, a paper co-ordinated by the Faculty of Sport Sciences of the University of Lyon (France) and the Interfaculty School of Sport Sciences of Turin appeared in the journal 'New athletic Research in Science Sport' (Bisciotti, 2007). [14] The article states:

"The effects of the controlled administration of vibrations on the human body have been known since 1949, the date of the first scientific work in this specific field. However, it was not until forty years later that the therapeutic value of vibrations was scientifically recognised with regard to their osteogenic effect, which justifies their application in geriatric medicine in general and in certain specific pathologies such as osteoporosis. Furthermore, the physiological effects induced by vibrations have recently been exploited to induce particular adaptations, in terms of increasing contractile strength in its various aspects, even in the sports field. A further, albeit not very well known, therapeutic field of vibrations is functional rehabilitation. The aim of this paper is to illustrate the neurophysiological principles of vibration work."

Today we can **define two forms** in which mechanical vibrations can reach our bodies:

1. The former is capable of powerfully and selectively stimulating certain types of nerve receptors involved in motor control. It is therefore limited to single muscles or small groups of adjacent muscles and is thus defined as **Focal Vibration (FV)**;
2. The second form involves the whole body. It is applied with a posture in complete functional unloading, with joints in decoaptation. It is applied in precise points, with targeted frequencies. This application, with limited irradiation and in symmetrical points, does not generate and propagate low harmonic frequencies, which are harmful to the structures of the human body, but only involves the stimulation of skin mechanoreceptors. This form is called **Multi Focal Vibration (Keope MFV)**.

5.1 FOCAL VIBRATION (FV): THE SCIENTIFIC PATHWAY

PV allows a very precise use of the vibrational stimulus. It is widely used in research to activate the proprioceptive system of individual muscles or joints. For a long time, attempts were made to use it for therapeutic purposes, as its action on neuromuscular spindles is well known15.

While the vibrating platform has a massive diffusion along the body, determined by a single source located in the plantar area, the PV and MFV, remaining confined to small areas, prevent the typical phenomenon of the propagation of mechanical signals through inhomogeneous structures such as biological tissues (fat, skin, muscles, bones, cartilage, connective tissue, etc.), i.e. the distortion of the applied signal. With PV, and also with MFV, we know which signal is applied, which nerve endings are stimulated and which signal reaches the centres.

In recent years, a number of parameters of PV have been identified that can persistently modify motor control. In particular, research has highlighted **three relevant aspects**:

1. As has already been amply documented by many authors16 , the frequency of the vibration must be a 'pure' signal, consisting of a single harmonic, i.e. a single frequency, capable of giving rise to a 'driving' phenomenon;
2. the effects only persist if a pure frequency between 90 and 120 Hz [17 is] applied (with regard to the stimulation of muscle tone);
3. The effects persist if stimulation is continued for at least 10 minutes [18]. In addition, PV and MFV are able to modify cortical excitability in area 15.
primary drive, both during the vibration and after the end of the vibration [19]. Some research groups have therefore tackled the problem systematically,

so as to define an application protocol capable of obtaining repeatable results and therefore assessable in the underlying mechanisms [20, 21, 22, 23].

5.1.1 FOCAL MECHANICAL VIBRATION (FV) AND MUSCULOTENDINOUS NERVE RECEPTORS

Muscles and tendons have two types of nerve receptors innervated by medium and large calibre fibres, i.e. with high conduction velocity, the neuromuscular spindles and the Golgi Tendon Organ (GTO).

The first, by means of sensitive fibres conventionally called Ia (primary, with a conduction velocity between 72 and 120 m/s) and II (secondary, with a conduction velocity between 24 and 72 m/s), would have the function of controlling the speed and extent of lengthening or shortening of the muscle fibres24 .

The latter, whose nerve fibres are referred to as Ib (with a conduction velocity of between 72 and 120 m/s), are considered to be intended to detect the stresses developed by individual motor units [25].

In 1963 Prof. R. Bianconi, the first professor of Human Physiology at the Catholic University of Rome, demonstrated how mechanical vibration, applied to a single muscle, at appropriate amplitudes and frequencies, was able to selectively activate primary (Ia) and secondary (IIb) spindle afferents or GTO, depending on the characteristics of the stimulus.

In addition, not only was it demonstrated that it was possible to activate selected classes of receptors in a completely non-invasive manner, but another aspect of extraordinary importance for research was revealed: **due to certain characteristics of frequency and amplitude of the applied vibration, these receptors generate frequencies of action potentials faithful to the frequency of the applied vibration**, **guiding the activated afferents to a discharge frequency identical to that of stimulation** (**the 'driving' phenomenon**).[26, 27].

Driving" allows you to drive a PRIMARY FUSAL AFFECTION at frequencies of 20 or 30 or 100 Hz, by applying vibrations at frequencies of 20 or 30 or 100 Hz, without having to use electrical stimuli or having to surgically isolate nerve fibres, but simply by applying a mechanical vibration to a single muscle.

With appropriate frequencies and vibration amplitudes, it is possible to select the activated afferents and determine the frequency of action potentials sent to the central nervous system.

For the first time it was possible to send to specific centres of the Central Nervous System (those that work by using information from the spindles and the GTOs) frequencies of predefined action potentials, choosing appropriately the parameters of the vibration, following, at the same time, non-invasive activation modalities and physiological afferent pathways. This was a radical change in the stimulation modalities of sensitive pathways compared to those carried out by means of bio-electrical stimulation on entire nerve trunks or even on single fibres, which are highly non-physiological and non-specific situations.

5.2 MULTI FOCAL VIBRATION (KEOPE MFV)

STRUCTURE DESIGNED TO CREATE POSITIVE EFFECTS INDUCED BY SEVERAL FOCAL MECHANICAL VIBRATIONS

Since 1991 the Centro di Ricerca sul Comportamento Umano (Centro A.M. di Sirtori - LC) has been working on the construction of an ideal ergonomic structure for the application of vibrations on the human body.

The human body can be considered as a system with n degrees of freedom. It does not vibrate as a single mass with a single natural frequency, but each mass, i.e. each part of it has its own specific resonance frequency, and therefore **the application of vibrations cannot be carried out starting from a single point of the body and then propagating the effects to the rest of the body.** Not only does this not produce the desired results, it also has negative effects on the entire body.

The optimum is achieved by localising the vibrations in specific areas of the body, in a very precise way, so as to focus the effect of the vibration in the desired area, where it is then necessary to apply the vibrations, avoiding unnecessary dispersion. As explained in the previous chapter, this is the central element behind focal application.

In recent years the AM Centre has identified a **new way** of applying vibration to the human body: Multi Focal Vibration, which works through **mechanical vibration at targeted frequencies**, applied **to specific areas of the body**, corresponding to precise insertions of muscle chains; **areas that involve the entire musculoskeletal system.**

This was made possible by a previous invention: Keope, the only essential ergonomic structure that allows the human body to assume **a posture of complete functional unloading**. This structure minimises contact with the body, thus eliminating unnecessary compression and improving blood circulation, lung ventilation and reducing cardiac work. In addition, this structure allows the **application of vibrations in decoaptation of the spine and large joints**.

The action of a number of micro-vibrators in specific areas with targeted frequencies makes it possible to maximise the beneficial effects of vibration, which have been demonstrated by the many scientific investigations of recent years.

Chapter 6

A PROTOCOL FOR APPLYING VIBRATION TO THE HUMAN BODY

As we have pointed out in the previous chapters, it has been known for more than 40 years that mechanical vibration localised to single muscles is capable of powerfully activating the musculotendinous proprioceptors. As this stimulus is completely non-painful and non-invasive, attempts have long been made to use this procedure to improve motor control. However, the improvements, when present, disappeared a few moments after the end of the vibration.

Recently, vibration parameters and an application protocol capable of inducing plastic, and therefore persistent, changes in motor control have been identified. These results open up new and unprecedented spaces for rehabilitation, since the control of joint rigidity largely escapes our awareness, and this constitutes a serious obstacle to the work of the physiotherapist.

The Institute of Human Physiology, the Catholic University of the Sacred Heart in Rome, and the Institute of Physical Medicine and Rehabilitation, La Sapienza University in Rome, carried out a series of experiments.

The results showed that exposure to this vibration for 10 continuous minutes, three times a day, for three consecutive days, is adequate to obtain the maximum effect with the shortest application time. It was also observed that a vibration of 30 minutes continuously, without even a short interval, markedly reduces the effects, probably due to the phenomenon of habituation. Because of this repetitive exposure to vibration, the name rMV (Repetitive Muscle Vibration) was introduced.

Lastly, the effects are only noticeable if the subject holds the muscle to be treated in slight voluntary, isometric contraction during the entire period in which the vibration is activated. Initially, this condition was chosen to facilitate the transmission of the mechanical vibration in the muscular context, thanks to the increase in rigidity induced by the muscular contraction and to increase the sensitivity of the neuromuscular spindles through the concomitant activation of the gamma circuits. Subsequently, it was attributed to
this aspect of the protocol a much greater role.

6.1 THE FIRST STUDY ON HEALTHY PEOPLE ON THE POTENTIALITY OF rMV: rMV's action on joint stiffness control

A double-blind study, decisive in defining the effects and understanding the mechanisms of action of this particular integrated system, consisting of a protocol and an 'ad hoc' device, was conducted on healthy subjects28, applying rMV to the Quadriceps muscle.

The study suggested that the action of prolonged vibration was able to modify persistently (tests performed 15 days after treatment) the motor control of the main joint treated. In particular, the subjects showed a marked increase (+40%) in fatigue resistance to repeated exercise (leg extension movements under load).

This increase was attributed to an improvement in the control of joint rigidity, induced by a reduction in joint impedance dictated by muscle coactivations. The parallel decrease in the rise time of the maximum force of isometric contraction (which remained unchanged, before and after the treatment) was attributed to the finer joint stabilisation, manifested by the probable reduction in coactivations, which allowed the nervous system to explode the strength of the Quadriceps more effectively.
In summary, the protocol developed presented some completely novel effects and suggested possible mechanisms. In particular, it was pointed out that:

1. the application of a low-amplitude vibration (< 0.1 mm), at 100 Hz, for 10 consecutive minutes, 3 times a day, for 3 consecutive days, is able to induce important and persistent changes in motor performance.
2. rMV appears to act directly on motor control, increasing joint control and in particular the control of joint stiffness.

The innovations introduced by this study were truly remarkable. In fact, this first study outlined an integrated system consisting of a protocol and a special instrumentation capable of inducing effects on motor control lasting at least 15 days and of great intensity in just 90 minutes.

In addition, the mechanism of action appeared to lie in a modification of the control of joint rigidity, thus in a direct action on the central nervous system and on a parameter: **joint rigidity**. Joint rigidity is one of the most complex parameters and20
determinants in motor control. In particular, the control of joint stiffness is the crux of motor rehabilitation, and is entirely managed outside the control

voluntary and therefore only modifiable by the therapist through indirect and therefore difficult, time-consuming and uncertain ways.

It is an aspect that affects almost all motor pathologies, such as spasticity or muscular hypotonia (respectively excesses and deficits in joint rigidity), and the consequences that these have on motor deficits, on quality of life, and on the obstacle that they represent for the therapist-patient duo in achieving correct motor strategies.
As a result of these deductions, the study was extended to situations in which joint stiffness was explicitly altered, either in the sense of a deficit or in the sense of an increase.

6.2 NEUROPHYSIOLOGICAL CORRELATES

Both of the above studies suggested that **rMV** was capable of **inducing** plastic **changes** in the central nervous system, particularly in **the control circuits of the treated muscle** and perhaps in functionally related **circuits.** These results made it essential to look for neurophysiological correlates to the data obtained from the motor performance study.

The mechanism triggered appeared capable of modifying the management of joint rigidity, a very complex control that requires the interaction of numerous groups of motor units belonging to anatomically different muscles, with fine and rapid modifications during the course of the motor act. **Plastic modifications of the nervous system had to be sought "upstream" in the central nervous system. Attention was therefore turned to the primary motor cortex** (M1).

Using a non-invasive and relatively simple technique, Transcranial Magnetic Stimulation (TMS), micro-areas of this region can be stimulated. The activated pyramidal cells in turn activate spinal motor populations and the electrical muscle signal evoked (Magnetic Evoked Potential, MEP) by such cortical stimulation can be recorded by surface EMG. It is thus possible to study the cortical extent of the areas involved in the control of particular muscles, their level of excitability and, by means of slightly more complex procedures, the control mechanisms exerted by cortical circuits on these same areas.

For this study, conducted by Barbara Marconi [29], researcher at the Fondazione S. Lucia and of the EBRI Foundation, together with other collaborators, rMV was applied to the muscle Radial flexor of the carpus on healthy subjects.

The application of TMS showed that the treatment with rMV stimulated intracortical inhibitory mechanisms on the areas related to the treated muscle, while the areas corresponding to the antagonist muscle (the common extensor of the fingers) were facilitated. **The effects were only present in the combination of voluntary muscular contraction + vibration** and persisted for at least 15 days, with a return to the pre rMV situation within 30 days of treatment.

The need to associate voluntary muscular contraction + vibration suggests that the plastic phenomenon is induced by an associative-type mechanism, which implies an associated activation of different cell populations.

From the point of view of functional significance, it is believed that an increase of inhibition in the intracortical circuits of M1 favours the identification of the muscles to be used during the movement, reducing the undesired contractions, or, in a more general sense, the undesired co-contractions. This mechanism is accentuated, naturally, by the processes of reciprocal cortical inhibition, whereby the activation of a muscle group inhibits the antagonist and vice versa. Treatment with rMV therefore appears capable of activating both these mechanisms, which, functionally, are believed to contribute to the regulation of co-contractions.

The mechanism of co-contractions is, for better or for worse, decisive in our movements, but it also constitutes, as already mentioned, a major problem in training and rehabilitation.

Co-contractions are crucial in regulating joint stiffness, but at the same time they cause greater energy and metabolic expenditure, lower muscular efficiency, greater fatigue, and lower execution speed. **The** results of the study with TMS therefore appeared to be consistent with what had been hypothesised in previous studies [30 31]: **rMV appears to be able to enhance motor control mechanisms, believed to be involved in joint control**.

The possibility that rMV produces a reduction in co-contractions and improved agonist/antagonist management is also consistent with the increased fatigue resistance and reduced force explosion times observed in healthy subjects.

The improvement of co-contractions, on the one hand indispensable and on the other an obstacle to motor execution, is very difficult, as is joint control in a broader sense.
These are adjustments that are beyond our control and depend22
entirely by the action of the central nervous system. Any intervention on them is therefore only highly indirect and therefore extremely time-consuming and tiring, as the characteristics of sports training and motor rehabilitation show. **The rMV, on the basis of these**

results, it appears to be able to act directly, rapidly and completely non-invasively on these mechanisms.

In Marconi's study the situation returned to that before rMV within 30 days, while the subjects with ACL reconstruction, followed up to 120 days after treatment, without repetition of the treatment, continued to increase their performance. These differences are probably due to the lack of possibility of consolidation of plastic effects in the case of treatment of the radial flexor of the carpus in healthy subjects compared to patients with ACL reconstruction. In the former, in fact, after rMV treatment, the treated muscle group continued to be used as before treatment. In the latter, rehabilitation further stimulated knee control. The neuromotor situation of the flexor of the carpus was therefore physiologically brought back to the "normal" situation in healthy subjects, while in the operated patients the rehabilitation pushed to increase and, above all, to consolidate the effects of rMV.

These considerations underline the importance of the interaction between rMV and exercise, based both on experimental data from the use of rMV and on what is known from neurophysiology.

To summarise, a few points appear relevant in the various research studies on rMV:

- ✓ **The rMV is a non-invasive protocol, based on a particularly low amplitude vibration**. Stimulation appears to be fully tolerable **from 4 years onwards**, easy to apply, although based on a very strict set of rules. Similarly, the parameters of the vibration must be completely constant and small variations can annul the results, which makes the instrumentation almost unchangeable from a technical point of view.
- ✓ MVR is not separable from rehabilitation, it is only a procedure intended to open new doors to rehabilitation by improving, through direct action on the central nervous system, the control of joint stiffness. Specific and targeted rehabilitation should make the most of what has been achieved. Subsequent treatment of a patient with rMV must be defined together with the therapists or, better still, implemented by the therapists themselves in accordance with the therapeutic concept.
- ✓ rMV is providing evidence of what rehabilitation has long been saying, namely that chronicity does not mean the end of improvements. Important results, often shown on video at conferences were obtained more than 10 years after the injury.
- ✓ The rMV for physiotherapy presents itself as an **opportunity to enter areas that are today almost abandoned:** the **over 80s**, chronic neurological injuries.

Chapter 7

POSITIVE EFFECTS OF VIBRATION ON THE HUMAN BODY

The musculoskeletal system is a complex biological machine for human locomotion. In order to perform and realise the various functional demands, this system is constantly changing its structure and metabolism, responding to use with changes in both form and strength. The two systems are designed to be able to withstand the same level of tension that the bone structure is subjected to.

Constant 'overload' (body movement) provides a biological stimulus through structural and metabolic factors, keeping the tissues, both bone and muscle, within a safe functional limit. Prolonged bed rest or immobilisation due to injury can weaken its structures to the point of limiting its functions. Some common diseases, such as osteoporosis or myositis, reduce the quality and quantity of bone and muscle structures, with the associated degeneration manifesting itself in clinical symptoms. When the daily loads to be sustained are drastically reduced, the result is a remarkable muscular atrophy whose half-life lasts about 8-10 days, with a selective degradation of the protein structure that forms the contractile component of the muscle, especially in the slow fibres. This is the main cause of the dysfunction and decrease in strength of both bones and muscles with the onset of old age.

It has been shown that exercise of short duration, but of very high intensity, has positive effects on bone, muscle and joint structures; so much so that both mass and strength are maintained at a high level in response to these cyclical efforts. However, humans are normally sedentary, especially in old age. And, often, his physical activity is reduced to simple locomotion for normal daily functions. **Daily human locomotion is the minimum mechanical stimulus that ensures basic muscle tone. That is why it is recommended that old people do a lot of walking**. This stimulus, which is generally required to overcome the force of gravity, **is barely sufficient to protect the bones from fractures**. In fact, during locomotion, on impact with the ground, a train of shock waves is generated and transmitted throughout the body. These vibrations are transmitted through the foot, leg, spine and neck. This represents a strong stimulus for the
formation of bones during human life. Unfortunately, **the modern understanding of**
of vitality stronglyincreases
movement activity, with a sharp rise24
hypokinesia and thus results in a negative effect on the musculoskeletal system. In order to compensate for the lack of movement, different

projects to stimulate and induce the population to increase physical activity, but unfortunately due to a lack of equipment and a wrong lifestyle this does not happen. Or in very small quantities. Often insufficient to avoid risks.

Research has shown that mechanical vibration is a powerful stimulus for the entire organism, especially the neuro-muscular and skeletal systems. The following is a summary of the main positive effects of mechanical vibration that have been found in scientific research over the last 40 years.

7.1 THE EFFECTS OF VIBRATION ON THE HORMONAL SYSTEM

As has long been known, there is a relationship between the sport practised and the athlete's hormonal profile. Repeated exercise is, in fact, capable of inducing a significant hormonal response, not only in terms of adaptation to the exercise itself, but also in the form of a long-term response to it.

Similarly, the application of mechanical vibrations to the human body is also capable of producing **an adaptive hormonal response**, producing, for example, **an increase in the plasma concentration of testosterone** (T) and **growth hormone** (GH), at the same time as a **decrease in the concentration of cortisol** (C). The **increase in T and GH is due to the action of the muscle metabo-receptors**, while the decrease in C is probably due to an insufficient stimulatory effect of the central motor command and nervous feedback in the skeletal muscles.

As reported in a study by Prof. Carmelo Bosco (2000), **the variation in the concentration of these hormones is also accompanied by an increase in the mechanical power of the muscles subjected to vibration**, leading to the hypothesis that, although the two phenomena occur independently of each other, they may have mechanisms in common.

Among the hormones whose secretion is strongly stimulated by mechanical vibrations, we should mention, first and foremost, **serotonin** (5-hydroxytryptamine), a biogenic amine derived from the decarboxylation of 5-hydroxytryptophan. Serotonin is produced by enterocromaffin cells in the intestinal mucosa and is present in the nervous system, smooth muscle and blood platelets. It is a powerful vasoconstrictor
local and has a general hypotensive effect, and also plays an important role in the haemostasis, stimulating the repair of injured vessels.

Vibration also stimulates **the production of neurotrophins**, a family of proteins, including NGF, that act **by regulating the natural cell death of neurons that occurs during development**. **Neurotrophins** are also **capable of stimulating the survival of distinct populations of neurons** in vitro.

Endorphins, opioid neuropeptides that mimic the analgesic and behavioural effects of morphine (morphine-like action), **are** also **strongly stimulated by vibration exposure**.

Lastly, we must remember that **vibrations stimulate the secretion of IGF-I, or somatomedin C, which is one of the two polypeptide growth factors** (the second being IGF-II) and consists of molecules made up of 70 amino acids, with 45% homology to insulin. **The physiological role of IGF-I is to mediate the action of growth hormone, stimulating skeletal development**.

7.2 THE EFFECTS OF VIBRATION ON SKELETAL MUSCLE SYSTEMS

During locomotion, on impact with the ground, a wave train is generated and transmitted through the whole body via the foot, the leg, the spinal column and the neck. This wave train represents a strong stimulus for the entire organism, especially for the musculoskeletal system, as it represents the minimum mechanical stimulation that ensures the maintenance of basic muscle tone. In fact, muscles and bones interact and react continuously under the action of a constant load, represented by the weight of the body.

When this daily load is lost, for example due to a prolonged period of bed rest or immobilisation caused by injury, the structures can be weakened to such an extent that their functions are restricted and lead, in particular, to muscular atrophy.

The application of high intensity, short duration mechanical vibrations has been shown to have positive effects on bone, muscle and joint structure such that both tissue mass and strength are maintained at a high level, resulting in reduced muscle and bone loss [32].

These changes in the neuromuscular response are mainly attributable to the increased **activity of the upper motor centres** and the substantial improvement of the nerve commands that regulate the neuromuscular response.

The mechanical vibrations, **applied locally to the muscle and/or tendon structure** (40 Hz), **cause the activation of the** muscle spindle receptors **at the level of the directly stressed muscle-tendon complex,** but also of the adjacent muscle groups.

This type of response by the muscle to vibratory stimulation is referred to as the 'tonic vibration reflex' (RTV).

It is scientifically documented that RTV induces an increase in the contractile force of the muscle groups involved, which results in a clear change in both the force-speed and force-power relationship [33].

Vibratory training can therefore be assimilated to a succession of contractions of small amplitude, which lead to modest but significant rhythmic changes in the length of the muscle-tendon complex subjected to vibration. This particular mechanical behaviour induces a facilitation in the excitability of the spinal reflex.

In fact, **some studies have proposed that RTV operates predominantly, if not exclusively, through alpha motor neurons** and does not use the same efferent cortical patterns as voluntary movement. However, **it is** also **possible that the RTV, induced by the vibrations themselves, induces an increase in the recruitment of motor units through an activation of neuromuscular spindles and polysynaptic activation** [patterns34].

7.3 THE EFFECTS OF VIBRATION ON BONE TISSUE

The skeletal system basically has three functions:

- the first is to provide mechanical support to muscles and tendons, so that movement is possible;
- the second is to protect vital organs;
- while the third is to provide an organic calcium reserve aimed at stabilising calcemia.

For these reasons, the skeleton, at any biological age, is not an inert mass but, on the contrary, a plastic entity in continuous renewal: just think of the process of bone remodelling during growth, or the need for suitable reparative phenomena in the event of a fracture, without forgetting the role of a reserve in the development of the skeleton. organic calcium

Plastic behaviour is orchestrated by two very specific physiological phenomena:

- osteorexorption, provided by osteoclasts;

- osteoformation due to the activity of osteoblasts.

The relationship between these two phenomena, which are physiologically antagonistic to each other, results in the possible maintenance, loss or acquisition of bone mass.

It has long been known that the mechanical factor plays a crucial role in the dynamic control of bone remodelling, allowing the bone structure to adapt to stress. For this reason, a decrease in mechanical demands on the skeleton can be a serious problem in terms of maintaining bone mass. For example, **plaster cast immobilisation can be the cause of significant and rapid bone loss, which is easily reversible in adults but largely permanent in geriatric patients**.

The mechanisms by which physical activity can positively influence the process of bone remodelling are relatively complex. From a cellular point of view it would appear that only osteoblasts are equipped with mechanoreceptors and that, for this very reason, they are able to respond positively to an increase in compression forces. For the same physiological reason, a decrease in compression forces is able to decrease osteoblastic activity, leaving the process of bone resorption unchanged.

The clear improvements in muscle function induced by the administration of vibratory treatments produce very effective stresses on the biological functions of the bones on which they are inserted; in fact, the force generated by the muscle tissue is strongly correlated to the development of bone mass and its capacity for mechanical resistance.

Bone structure subjected to a high level of mechanical stress, as in the case of intense exercise, is able to suppress the bone remodelling mechanism, thus facilitating the conservative process. However, only intense and prolonged training has been shown to positively influence bone mineral density (BMD). The effectiveness of muscular exercises is especially evident in the transverse axis, which is the weakest and therefore most prone to fractures.

Due to their high intensity and duration, physical exercises are not well suited to an elderly population or individuals with fractures.

The application of vibrations, on the other hand, allows an intense stress on the skeletal and muscular system without requiring a high degree of commitment from the patient, thus proving to be a particularly suitable intervention strategy in certain cases. Even if a clear and unambiguous explanation of the phenomenon, **the action of mechanical vibrations on the mechanisms of bone remodelling is evident and has been reported in many clinical studies in patients**

with bone fractures or osteoporosis. In both cases**, subjects treated with vibration therapy showed a real increase in osteogenic activity35** .

The application of vibration therapy is therefore able to positively interfere with bone metabolism, even in the presence of osteoporotic degeneration and, given the evidence that vibration therapy is able to promote an increase in BMD, **it can be said** that this is **a therapeutic means of choice in geriatric medicine within the framework of therapies for the treatment and prevention of osteoporosis**.

Osteoporosis is a metabolic osteopathy with a complex aetiology, characterised by a localised or generalised reduction in bone tissue, whose osteoid matrix, as a result of an imbalance between the speed of synthesis and the speed of degradation, while remaining normally mineralised, is quantitatively reduced. On radiological examination, a rarefaction of the bone, a thinning and numerical reduction of the trabeculae and an increase in the medullary spaces are visible. A distinction is made between an age-related and post-menopausal form and a form secondary to prolonged immobilisation or endocrine disorders. In the female population in particular, the oestrogen deficit during the menopause causes an accelerated bone turnover and a loss of bone mass, which is why osteoporosis affects one in four women, while in the male population the ratio is one in eight. **Osteoporosis, given the progressive increase in the average age of the population, has now taken on the dimensions of a real socio-economic problem**, **which afflicts the elderly population (and others) worldwide.** In Italy alone, the social cost of this disease amounts to five hundred million euros per year. **Exercise is strongly recommended for patients suffering from osteoporosis,** both as part of its treatment and as a **form of preventive therapy**. In fact, the physiological **mechanical stimulation induced by exercise** proves to be **particularly useful both in limiting bone loss** and in **stimulating an increase in bone mass.** Osteoporosis, in fact, is accompanied by an increased susceptibility to fractures.

Precisely because of the effects it has on osteoporotic patients, mechanical vibration can also (and above all) be applied with astonishing results to patients with fractures of the upper and lower limbs. Vibration, in fact, induces an acceleration of bone growth that allows the fractured bone to be welded in a much shorter time than normal, with obvious clinical and economic benefits first of all for the patient, but also for the National Health Service. We would like to point out that the incidence of hip fractures due to simple falls in the population is as high as in the United States.
elderly, figures in the order of 90%, without taking into account the so-called hip fractures caused

by bone reduction due to osteoporosis alone, so vibration in this case is extremely important and useful [36].

7.4 THE EFFECTS OF VIBRATION ON THE ELDERLY

In elderly subjects, the mechanoreceptors located at the level of the osteoblasts, which normally respond to an increase in the forces applied, decrease their response with the same overall load; in this way the osteoblastic activity progressively disconnects from the osteoclastic activity, thus inducing a cascade of physiological phenomena which result in a more or less important loss of bone mass.

Moreover, it is well known that the ageing process leads to a progressive sedentarisation of the individual's lifestyle, and also to **various diseases**, including (as mentioned above) **osteoporosis**.

The ability of rMV to act on the control of co-contractions has suggested two apparently opposing areas of intervention, but in reality with a common denominator, altered joint control: **the instability of the elderly and neurological pictures characterised by spasticity.**

Poor joint control in spasticity is essentially evident in the imbalance between agonists and antagonists and in dyssynergy. **In the elderly, poor joint control undoubtedly plays an important role in the loss of stability and diminished strength**. The loss of stability, in particular, is of considerable importance, since **the problem of falls is an enormous social cost**: the resulting **femur fractures** alone cost over **one billion euros** each year in direct and indirect costs**,** and **over 16,000 over-65s die each year**. In addition, the picture of instability in the elderly is a typical vicious circle that is accelerated by falls. The person feels weak and unstable, so he reduces his physical activity and also his daily activities. This reduction accentuates fatigue and instability and the circle closes.

For a long time, attempts have been made to make up for this deficit by trying to increase the strength of the subject by means of high-impact training, which is, however, hardly acceptable for elderly subjects. In more recent times, however, evidence has been given of the role that co-contractions play in the elderly and in the loss of proprioceptive control that develops. In fact, **the loss of control (therefore this more than the loss of strength) pushes the elderly to stiffen up, making greater use of co-contractions. Paradoxically, it can be said that the elderly person stands with strength rather than balance**.

The first study on the effects of rMV treatment on the elderly was carried out at the University of Perugia, in collaboration with the Catholic University and the Sapienza University of Rome. Also in this study, presented in preliminary form in 2004[38] and now under review in Eur J Appl Physiol, conducted in a double-blind manner and using both rMV and a false stimulation, the **quadriceps of women over 60 years of age were** stimulated. The patients **received only one rMV treatment** and none of them participated in physical activity programmes before treatment and during the study period (90 days).

Also in this case, 24 hours after the end of the treatment, the analysed indices (power in jumping and body oscillation in monopodalic posture) were significantly improved and **in the following 90 days the improvement was accentuated, reaching and maintaining until the 90th day of the study an increase of about 35% in leg power and about 40% in stability.**

The long maintenance of the results in this case was attributed to the consolidation of the plastic effects, due to the spontaneous increase in simple daily activities. **The participants treated with rMV** (no effect was observed in the other two groups), although not undergoing any specific training**, all reported to move with less effort and more ease during the day, for shopping, cleaning the house, climbing stairs** etc.. The picture suggests that rMV has broken the vicious circle described, favouring the increase and maintenance by consolidation of the plastic effects.

In addition to confirming the hypotheses formulated by Marconi and co-workers, this study revealed a **marked increase in leg power**. The latter can be explained by better joint stability and reduced co-contractions, but the question was raised as to whether there could also be better **recruitment of motor units**.

The latter hypothesis was in fact confirmed by a new study with TMS, again conducted by Dr Marconi's group and currently being written up.

Subjects over 65, subjected to rMV present a significant reduction of the threshold in the neuronal populations controlling the Quadriceps, parallel to an increase in intracortical inhibition and reciprocal facilitation of the leg flexors. The improvement of these three parameters, which typically worsen with age, and their persistent improvement for at least one month (in elderly subjects TMS is very uncomfortable and it is not possible to carry out many tests), profile an action of contrast of rMV against a motor deterioration typical of ageing. At the same time it is shown that this deterioration is by no means irreversible and, on the contrary, there are considerable plastic reserves even in the Central Nervous System of elderly subjects.

7.5 THE EFFECTS OF VIBRATION ONOBESITY AND OSTEOPOROSIS

From the most recent studies conducted by Prof. C. Rubin (2009), we learn that low magnitude **mechanical signals** (LMMS) are able to **suppress the growth of subcutaneous and visceral fat,** while promoting **bone regeneration**. These processes take place thanks to the direct **stimulation**, by mechanical signals, **of pluripotent mesenchymal stem cells** (MSCs), which are immature cells with the ability to self-renew and continuously differentiate into specialised tissue-specific cells. Among the many differentiation pathways, **these cells give rise to osteoblastogenesis and adipogenesis**, which lead to the **formation of osteoblasts and adipocytes respectively**.

Mechanical stimulation of MSCs activates osteoblastogenesis in a directly proportional manner and adipogenesis in an indirectly proportional manner, through the activation of the Runx2 transcription factors for osteoblasts, which promotes differentiation, and the PPARγ factor for adipocytes, which suppresses it. **In this way, this method can be a safe, non-invasive and non-pharmacological strategy to prevent obesity and osteoporosis** [39].

With regard to the latter pathology, a study was recently carried out (Foti C, Annino G, Bosco C et al., 2009) on a group of osteoporotic women to show the positive effects induced by vibratory treatment combined with physical activity. This study involved 26 women aged 63 years, suffering from this pathology. They were divided into two groups, a control group and an experimental group. All of them underwent a training programme of one hour three times a week for four months, and only the experimental group was subjected to low-intensity vibration at a frequency of 30 Hz following the training. At the end of the study, the experimental group showed an increase in bone density, while in the control group there were no significant changes. It was therefore demonstrated that **this method**, combined with physical activity, is **a strong, non-invasive and the only non-pharmacological intervention for the treatment of osteoporosis**.

7.6 THE EFFECTS OF VIBRATION IN PAIN THERAPY

The analgesic effect of the vibrations is based on the theory of "gait control", which Melzack and Wall put forward in 1965 and on which the scientific rationale for TENS (Transcutaneous Electrical Nerve Stimulation) currents is based. Just as in the case of the use of

In the case of TENS, the vibrations would also be capable of producing a kind of afferent barrage along the type Ia myelinised fibres, of such intensity that it could be defined as a true 'busy line' effect[41].

From a clinical as well as an experimental point of view, it would seem to be justifiable to affirm that vibration has a neurophysiological effect, but only a segmental one. This assertion is also supported by the rapidity with which the analgesic effect is recorded, and by its equally rapid decline, factors which would testify to the "pure" spinal segmental inhibition exerted by the vibrations on the Ia afferents, as far as the transmission of nociceptive input is concerned [42].

Vibrations, the use of heat and cold and electric currents are the methods most frequently cited in the literature as a means of peripheral stimulation for analgesic purposes [43], although vibrations appear to be the least used of these methods. In the bibliography it is possible to see that vibrations have been used mainly for analgesic purposes in headache pain [44], in musculoskeletal pain [45] [46] [47], in some painful pathologies of neurogenic origin and in low back pain [48] [49].

The time required to apply the vibrations for analgesic purposes varies, depending on the various experimental work protocols, from 5 to 30 minutes, while the frequency value generally considered most effective for this purpose is around 100 Hz. Generally speaking, the application technique calls for the vibration to be carried out homolaterally on the dermatomere on which the site of pain is registered, applying a certain amount of pressure with the vibrating device. After 5 minutes of vibratory application, the pain disappears or, at least, subsides considerably, only to reappear 5-10 minutes after the end of the application. On the contrary, if the vibratory application lasts 30 minutes, the antalgic effect can last up to 5 hours [50] [51]. **It is** also **interesting to note** that **in low back pain of medium intensity** and not associated with radicular compression, **the application of vibrations at 100 Hz** frequency and amplitude of 1.5 mm, by means of a vibrating cylinder **positioned on the Achilles tendon, is able to drastically reduce the intensity of pain in a short time52**.

7.7 THE EFFECTS OF VIBRATION ON BLOOD CIRCULATION

The application of mechanical vibrations on the body also produces an **increase in blood circulation**, with an increase in the average speed of blood flow and a considerable lowering of the Resistance Index, measured by Doppler examinations.

However, as no increase in maximum velocity was found within the individual vessel, it is possible that the increase in average velocity is due to the dilation of smaller blood vessels, thereby reducing peripheral resistance.

This increase in blood circulation has beneficial effects on metabolism, oxygen supply to the tissues and helps to lower blood pressure.

This makes vibrations particularly suitable in cases of circulatory disorders such as arteriosclerosis or poor lymphatic drainage.

Chapter 8

RESEARCH AND APPLICATION OF MECHANICAL VIBRATION BY ITALIAN UNIVERSITIES

Report of the Congress of 13 December 2008 published on "Paginemediche.it".

SIMPLE, REPEATED MECHANICAL VIBRATIONS INCREASE BRAIN FUNCTION, IMPROVING MUSCLE AND JOINT CONTROL [53]

New and encouraging results of a procedure called 'rMN' (Repeated Muscle Vibration), obtained in the fields of neurology, orthopaedics, stability in the elderly and recovery from fatigue in healthy subjects are published in the December issue of the Journal of Neurological Science. The studies were carried out by researchers of the Institute of Human Physiology of the Catholic University of Rome, in collaboration with Fondazione Santa Lucia and EBRI, University of Perugia and University La Sapienza of Rome.

The physiological foundations and results of the procedure were presented at the Scientific Seminar entitled "Proprioceptive Stimulation, Control and Motor Rehabilitation. New clinical evidence and neurophysiological correlates', which took place on Saturday 13 December 2008 at the Policlinico universitario Agostino Gemelli, promoted by the Catholic physiologist Guido Maria Filippi. Speakers: Prof. Vito Enrico Pettorossi (Institute of Human Physiology, University of Perugia); Dr. Filippo Camerota (Institute of Physical Medicine and Rehabilitation, La Sapienza University of Rome); Dr. Diego Ricciardi (Department of Gerontological and Geriatric Sciences - Policlinico Gemelli, Rome).

The protocol is based on a specific instrument, which develops a sequence of mechanical signals of very small amplitude, which are read by specific nerve sensors in the muscles and sent to the central nervous system. What appears to be a small mechanical vibration is actually a code capable of reprogramming selected areas of the nervous system. This procedure is the first to act in a simple, non-invasive and persistent way on the nervous controls of the muscles. This stimulation, thanks to studies conducted by Dr. Barbara Marconi (Fondazione Santa Lucia and EBRI) and Prof. Guido M. Filippi (Università Cattolica), is able to modify the function of specific cortical areas of
motor control, activating mechanisms that can lead to a marked improvement in motor performance.
motor functions.

These results (now published in the Journal of Neurological Sciences) were observed by the researchers Marconi and Filippi in healthy subjects, in patients affected by chronic stroke outcomes (spasticity), even years after the damage and in subjects over 70. This is the first experimental evidence of the existence of such a possibility, which, moreover, can be achieved with a simple, non-invasive procedure, substantially free of side effects. The procedure based on localised micro-vibrations, which the researchers have named 'rMV' (Repeated Muscle Vibration), was developed by Professor Filippi, a lecturer at the Institute of Human Physiology at the Catholic University of Rome. The application of particular sequences of micro mechanical vibrations to certain muscles of the body is able to increase the functions of certain areas of the brain, improving muscle function.

The protocol

This procedure, which is very simple to carry out (the protocol involves applying the micro-vibration 3 times a day, 10 minutes each time, for 3 consecutive days to the individual muscles on which it is desired to act), has proved capable of producing positive and surprising effects in a very wide range of situations: in the neurological field, post-stroke rehabilitation and spasticity and flaccidity, in controlling the sense of fatigue and pain and strength in elderly people at risk of falling, and in orthopaedic pathologies.

This strengthening is 'long-term', because after a few minutes of stimulation, it is maintained over time for weeks and months. Subsequent use of this enhancement (physiotherapy, training) consolidates, reinforces and maintains the effects for months, in some situations for many months.

Results in neurology, orthopaedics, the elderly and healthy subjects

More specifically, in the neurological field, on the basis of the data currently available, rMV has been shown to be able to increase motor control of what is left over from a neurological lesion in subjects who have retained even minimal residual voluntary motility. There have also been significant improvements in subjects with spastic forms (from stroke, trauma), but with residual voluntary movements.

In the orthopaedic field, the procedure has proved to be very effective in situations where immobilisation, following operations, or joint pain lead to poor muscle use. For example, preliminary studies conducted at the Policlinico Gemelli in Rome have shown reductions in pain in severe arthrosis of up to 50% just 2 weeks after treatment.

In the studies carried out so far by researchers at the Cattolica University together with colleagues from the University of Perugia (Prof. Enrico Pettorossi) and La Sapienza University of Rome, the treatment of rMV concentrated on the quadriceps has resulted in a significant increase in the number of elderly people.

collaboration with the Municipality of Rome, the increase in power was 70-75% and stability 30-35%. In particular, a study conducted on 200 over-65s in the Elderly Centres of Rome showed a decrease in the risk of falls in 83% of subjects and a return to normal in 89%. However, the improvement in muscular performance is not limited to pathological or debilitated subjects, but can be extended to healthy subjects or sportsmen. Treatment with rMN showed increases in fatigue resistance of more than 40% and increases in explosive strength of 27% in young individuals who had not undergone any form of training in the months preceding the study and during the study.

"Although the applicability of the procedure may seem extensive and the extent of its effects surprising - explains the physiologist of the Catholic University Filippi - it must be remembered that, as shown by the studies carried out in collaboration between EBRI and the Catholic University of Rome, the procedure strengthens the nerve networks and mechanisms that regulate muscle control, minimising unnecessary contractions (present in spasticity, in the elderly who are afraid of falling, in subjects who have not acquired an adequate level of strength).
"fluidity' in the athletic gesture), by promoting the recruitment of muscle fibres (which is lacking in sedentary people due to habit or therapeutic constraints). It is therefore a direct and targeted action on selected nerve networks, which play a primary role in controlling and coordinating our every movement. In order to eliminate any false expectations," warns Filippi*, "it must be said that the treatment can neither perform miracles nor replace traditional rehabilitation. rMV opens new and important doors for physiotherapy, which must therefore intervene in a specialised manner that is appropriate for the individual patient".*
"Improving the function of specific areas of the brain means improving the performance of our motor muscles in terms of strength, resistance to fatigue and coordination. In particular, poor co-ordination is expressed in spasticity, muscle tears, poor joint function, and this leads to pain, arthritis and arthrosis. So acting on coordination means acting on the quality of life,' explains physiologist Filippi.

The rMN vibration has strict parameters: the application of the micro vibration 3 times a day, 10 minutes each time, for 3 consecutive days to the individual muscles you wish to act on, including a frequency of 100 cycles per second. The instrument allows this vibration to be produced and, above all, to be delivered to the muscles as it is, without excessive distortion.
"This localised vibration of individual muscles,' adds Filippi*, '*is a mild but powerful stimulus for the hundreds of nerve sensors in the muscles. These 'read' the 100 cycles per second and send them to the nerve centres controlling the treated muscle. The frequency used*
constitutes a 'code' for these centres, the effect of which is an enhancement of the nerve control networks. The Central Nervous System becomes 'better' at controlling and coordinating muscle bundles'.

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