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THE MECHANICAL VIBRATION THERAPEUTIC EFFECTS AND APPLICATIONS

Editor:
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The Mechanical Vibration: Therapeutic Effects and Applications

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FOREWORD

Vibrations. Good vibes. Bad vibes. Too much of vibes. Not enough of them. When I first heard of vibrations, I was in my teens, and it was all about the good vibes coming from great music bands. After that, as an orthopaedic trainee, I was taught that vibrations were bad: helicopter pilots and truck drivers were exposed to exactly the kind of vibrations which induced asynchronous contractions of the back muscles, and had direct deleterious effects on the vertebral discs. The result includes low back pain and osteoarthritis of the lumbar spine. Following this, somebody had the great idea to test vibrations in clinical practice. Lo and behold, some science was injected into vibration science, and it was found that if too much is not too good (actually, it is pretty bad), a measured amount of the right kind of vibration can bring good. Prof. Saggini has been on the forefront of this “good vibes movement”.

Prof. Saggini is a thoughtful, skilled clinician, armed with foresight and rigour. He started observing and experimenting, and has been able to produce much of the present day scientific evidence on this fascinating topic. “Mechanical vibration: therapeutic effects and applications” show, as Prof. Saggini would say, that “nothing rests”. Indeed, we are moving all the time, and vibration is at the centre of our life.

Progressing from the basic sciences of vibration, the scene is set for clinical applications, in a variety of forms. The truth, however, is that: this edition of “Mechanical vibration: therapeutic effects and applications”, provides the beginning, and, through the strict scientific work that Prof. Saggini will continue to perform, more truth will come out of it.

Enjoy!

Nicola Maffulli
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PREFACE

Current evidence shows that the entire Universe vibrates; gravitational waves may be regarded as ripples in the curvature of space-time propagating in an oscillatory fashion and travelling outward from the source.

Any given complex body is capable of vibrating in several different ways, each one being characterized by its own frequency.

The inorganic matter is made up of atoms that are in a constant state of motion; depending on the atomic speed, inorganic matter will exist in a solid, liquid, or gaseous state. By the same token, the human body is made up of atoms in continuous vibration, the latter being necessary for the homeostatic maintenance of the organism.

Several essential cellular processes, including cytoskeleton activity, enzymatic reactions, chromosome packaging and replication, nucleic acids transcription and translation, and protein folding and unfolding, generate forces resulting in intracellular movement. For instance, protein polar oscillation during cell division and cytoskeleton assembly greatly contribute to such intracellular dynamics by generating polarizing ionic currents and charge-induced nanoscale movements. The net effect of these events is the vibration of the entire cell and its components.

It is currently thought that the transduction of intracellular movements allows the cell to emit vibration waves carrying information about intracellular metabolic status. The latter mirrors the energy internal to the cell, being the proportional to intensity and frequency of the ensuing vibrations.

Mechanotransduction analysis assesses the causal relationship between mechanical forces, intracellular signaling, and subsequent changes in cell behavior. Indeed, mechanical forces seem to play a crucial role in several aspects of living tissues, including organization, growth, maturation, and normal functioning.

Physical signals are known to travel faster than signaling through chemical mediators, the latter being limited by dependence on diffusion. Accordingly, physical signals appear to represent a more effective way of cell signaling whenever a rapid response is required.

The human body is constantly subjected to vibrations deriving from the surrounding environment, including sources such as industrial machinery as well as common means of transport (terrestrial, nautical, and aerial). Overall, such vibrations may be viewed as different forms of the same primitive mechanical oscillation – *i.e.*, endless “variations on the theme” acting at both the macroscopic and the microscopic level. Any vibration or oscillation will induce a tuning response by the cell through changes in signal transduction, resulting in potentially healthy (therapeutic) or adverse effects. Indeed, to quote Paracelsus, «*Omnia venenum sunt: nec sine veneno quicquam existit. Dosis sola facit, ut venenum non fit*».

In sum, it appears indisputable that nothing rests: everything surrounding the human body vibrates at an exclusive frequency, and so does the human body. Accordingly, it seems crucial to develop a deeper understanding of the physical parameters of vibration (amplitude, frequency, direction of the stimulation, and duration of the exposure), as well as to gain better knowledge regarding ways to modulate vibrations in order to improve body homeostasis by means of:

- relief of pain and pathological inflammation, both acute and chronic;
- bone and soft tissues regeneration, and musculoskeletal functional improvement;
- amelioration of common neurological diseases, including motor impairment.

My hope in writing this book is to clarify further the medical role of vibrations in improving human health.

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My sincere thanks to all co-authors, Nicola Maffulli for the Foreword, my wife Susanna Morici Saggini whose constant encouragement and sustain my life.

The excellent staff of Bentham Science Publishers.

ABOUT THE EDITOR

Professor Raoul Saggini was born in 1953 in Florence, where he graduated in Medicine and Surgery in 1979. Later he specialized in Orthopedics and Traumatology, Physical and Rehabilitation Medicine, Sports Medicine, always obtaining the highest grades and honors.

At the University of Florence, Institute of Orthopedic Clinic, he performed activities initially as intern (1979-'81) and later as an Assistant Professor. In this period he carried out scientific activities taking care of foot surgery, orthopedic aspects of some genetic diseases and knee arthroscopic diagnostics. In 1986-'90, at the Institute of Orthopedic Clinic of the University of Florence, and in collaboration with the Institute of Orthopedic Clinic of the Catholic University of the Sacred Heart in Rome, he carried out scientific activities concerning the field of biomechanics of the human body movement and study of gait analysis.

Since 1991, he has continued the academic research and teaching at the "Gabriele d'Annunzio" University of Chieti-Pescara, Italy. Today in the same University he is Full Professor, President of the degree course in Physiotherapy, and the Director of the School of Specialty in Physical and Rehabilitation Medicine.

He is also a permanent member of the National Commission for the Degree Courses in Physiotherapy, and National Coordinator of Schools of Specialty in Physical and Rehabilitation Medicine, as well as Coordinator of the Rehabilitation in Sport sector of the Italian Society of Physical and Rehabilitation Medicine (SIMFER), and former President of the Italian Society of Shock Wave Therapy (SITOD).

The current research activity ranges from posture and applied body dynamics, treatment of acute and chronic overload diseases of foot and trunk and musculoskeletal pain syndromes, to rehabilitation approaches during cancer treatment and therapeutic aspects of major neurological disabilities. Furthermore, in the field of research on advanced physical therapies and applications on human body to create an increase in homeostasis during the pathological state.

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CHAPTER 1

The Study of Vibrations: Mathematical Modelling and Classifications

Enrico Corsetti* and **Michele Casciani**

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Abstract: The matter is made up of particles, firmly assembled, as in the solids, or rarefied, as in the gases. When a force acts on a particle it moves determining different physical phenomena depending on the different characteristics of that particle and the surrounding ones.-This model represents the action of a blast or a mechanical pulse, just one hit and the system can manage the supplied energy by damping and distributing it.

Each system has a specific behavior, mainly depending on the frequency of the stressing force; if the system has a frequency of resonance whose value is close to the frequency of the stressing force, energy is stored in the system, movements of the particles become larger and, at the end of the energy supply, the system continues to oscillate, giving back the stored energy, implying that the longer the oscillation the lower is the damping.

The vibration of a physical system can propagate the movement through a vibrational wave, generated by the application of external forces generating internal stress, strain and reaction, a *disturbance* that travels through a medium from one place to another like a wave. When the vibration is forced by a mechanical system, the stimulus can be applied in order to generate a different kind of vibration. In order to generate a vibration, it is necessary to apply an external force: however, the response of a mechanical system to an external force can vary not only depending on the nature of the stimulus, but also according to the composition of the system itself. The mathematical model of a vibration system may take the form of acoustic waves.

Keywords: Mathematical modelling, Matter, Vibrations, Ways of propagation.

Matter is made up of particles, tightly assembled, as in the solid, or rarefied, as in the gases. When a force acts on a particle, it moves it, but the other particles of the whole system try to limit its movement, propagating its momentum in the same

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direction of the acting force (transmission), distributing its momentum among the other particles (absorption), degrading its phase and propagation direction (diffraction) or bouncing it back (reflection) [1] (Fig. **1**).

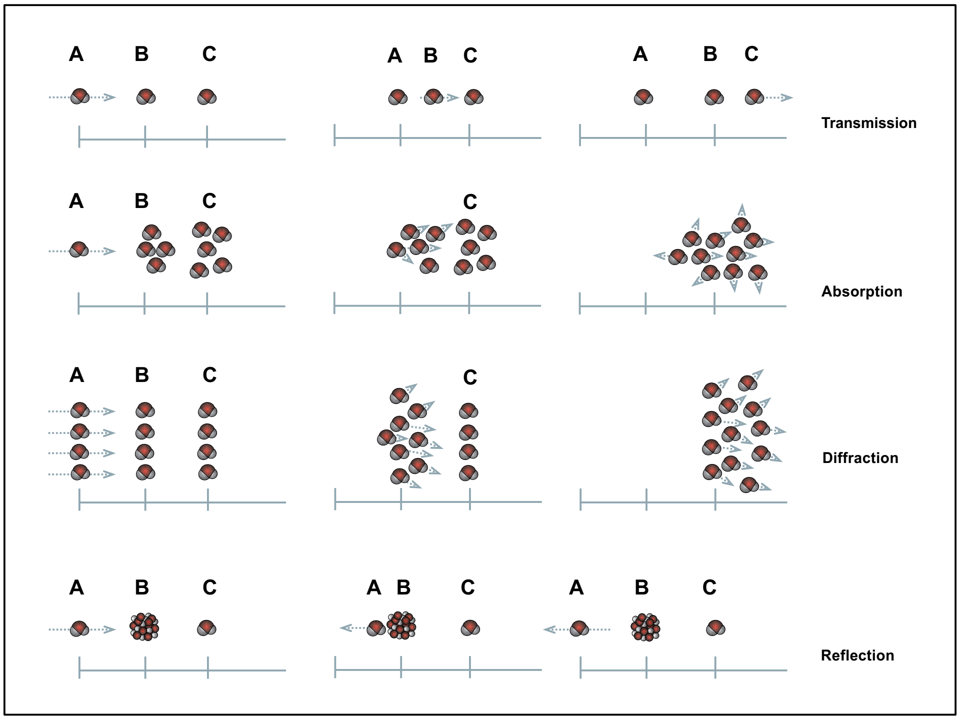

Fig. (1). Energy distribution of the whole system when a force acts on a particle.

This model is the action of a gust of wind or mechanical impulse, one shot and the system can handle the energy provided by damping and distribution.

If the force is applied for a duration longer than the time of strain it decays and if it is, eventually, variable in time, the system can react and store part of the supplied energy, starting a vibrational movement/strain variable in time. From an energy perspective, in a time longer than decay time, the supplied energy is equal to the distributed energy.

Each system has a specific behavior, mainly depending on the frequency of the stressing force (harmonic oscillation); if the resonance frequency of the system has a value which is near to the frequency of the stressing force, energy is stored in the system. So the movements of the particles become larger and, as the energy supply stops, the system continues to oscillate, and releases the energy previously stored, implying that the longer the oscillation is the lower the damping.

Matter transmits variable applied oscillating forces, through propagating waves, and it is able to store part of the supplied energy as static waves: the latter are good for resonators in order to reach a sharp frequency, a larger and steady amplitude, a phase variation, but are not good when the medium has to transfer energy, *i.e.* when the medium is a feeder.

In the latter case, resonances must be avoided either by increasing the propagation resistance (absorption related to damping) or keeping the transmitted signals away from resonance situations.

A mechanical vibration is a periodic back-and-forth motion of the particles of an elastic body or medium (*i.e.* with a mass and volume). The phenomenon occurs when the physical system is displaced from its equilibrium condition and responds to the stimulation with an internal motion that tends to restore equilibrium.

This general assumption has to be completed with the consideration that the medium has an elastic behaviour; this means that the particles in the solid can periodically and symmetrically oscillate around their position of a small Δx ($\Delta x = x_f - x_i$, where x_f is the final position and x_i is the initial position). The possible change in the solid position and shape generates a reaction force which is able to restore the original configuration.

Whereas the elastic behaviour releases all the energy stored by the body deformation, plastic behaviour keeps part of the deformation/strain permanently and releases only part of the supplied energy.

In physical systems, only small forces/strains/displacements can be considered as elastic.

The vibration of a physical system can propagate the movement through a vibrational wave, which is generated by the application of external forces generating internal stress, strain and reaction, a disturbance that travels through a medium from one place to another like a wave.

Vibrations can be divided into two main categories: free and forced. Free vibrations occur when the system is transiently disturbed by an external force (such as an impulse) and then allowed to move without restraint. A classic example is the mass-spring system. In the equilibrium position, the system has minimum energy and the mass is at rest. If an impulsive force is applied to the mass, the system will respond with a periodic vibration around the initial position, CHAPTER 2

The Applied Mechanical Vibration as Whole-body and Focal Vibration

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Abstract: The mechanical vibration is the simplest and purest form of vibratory energy application in physical and rehabilitation medicine. After the first observations of the effects of vibrations, the scientific research has been directed to the identification of the molecular mechanisms that mediate signal trans-duction at the tissue level. Although these mechanisms are still not fully understood, and despite the adverse effects observed in subjects improperly exposed to vibratory sources for various reasons, during the last century, the mode of application of mechanical vibration has gradually evolved from whole-body to focal and mechano-acoustic forms, as much as the field of application has gradually expanded spreading from the initial skeletal and muscle applications to the current motor impairment conditions associated with the most common neurological diseases.

Keywords: Amplitude, Focal vibration, Frequency, Mechanical vibration, Mechano-acoustic vibration, Mechanoreceptors, Mechanostat theory, Muscle spindle, Musculoskeletal system, Neurorehabilitation, Resonance, Somatosensory cortex, Tensegrity, Tonic vibration reflex, Tuning response, Whole-body vibration.

INTRODUCTION

The musculoskeletal system is a complex biological machine designed for movement and locomotion. This system is structured in such a way to respond with modifications both in metabolism and in structure to the functional needs of

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the organism and to the stresses transmitted from the environment, according to the principle of the so-called "Wolff's law", for which «form follows function» [1].

To describe the conditions that allow the maintenance of the system, a theory of the stimulus of everyday stress was formulated, which describes the intensity of a mechanical stress in terms of stimulation of daily stress. According to this theory, if a stimulus stressful for the system is greater than a threshold stimulus, the homeostatic balance will be positive (and oriented towards anabolism), while if the stimulus is lower than the threshold stimulus, the homeostatic balance will be negative (and oriented towards catabolism). When daily loads to be supported are drastically reduced (as occurs in disuse for palsy or immobilization, chronic degenerative diseases, or in case of reduced gravity), it results in degradation of the protein structure that forms the contractile component of the muscle and changes in microarchitecture of the bone, with reduced muscle tone and bone mass.

A type of mechanical stress is represented by vibratory stimulation. From a purely mechanical point of view, vibration is the mechanical oscillation of some measure or mobile body around an equilibrium point; the oscillation being the motion that it makes to return to the starting position. In a mechanical model constituted by a body of mass m, bound to a spring whose elastic constant is denoted by k, and put into oscillation, the mass m moves with regularity with respect to the reference position. In addition, the movement may reproduce self-identically to regular time intervals, having a so-called "periodic character" (Fig. **1**).

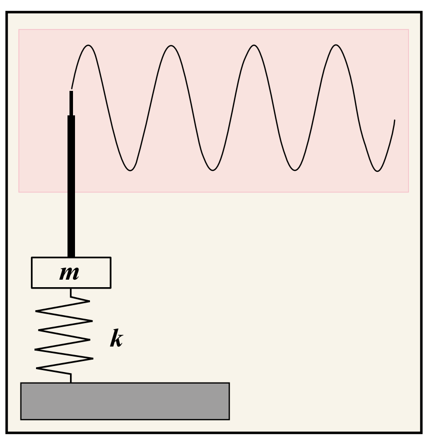

Fig. (1). In a system consisting of a mass constrained to a spring and placed in oscillation it will produce a smooth movement of a periodic nature.

The simplest periodic function is the *simple* or *natural harmonic motion*, whose trend in function of time is represented by a *sinusoid* or *sinewave* with constant amplitude and period. In a periodic oscillation, *amplitude* or *magnitude* is the maximum extent of the motion (peak-to-peak displacement of the wave, measured in millimeters), whereas *period* is the duration of time between two consecutive passages of the mobile body at the equilibrium point (a cycle) and is the reciprocal of *frequency*, that is the number of cycles per unit of time; thus, period and frequency are related through the following relationship:

$$f = 1 / T$$

Where f is the frequency (expressed in Hertz, Hz), and T is the period (usually measured in seconds). Frequency has also an inverse relationship to the *wavelength*, that is the spatial period of the wave (usually determined by considering the distance between two consecutive crests, troughs, or zero crossings):

$$f = v / \lambda$$

Where f is the frequency, v is the propagation velocity, and λ (lambda) is the wavelength (Fig. **2**).

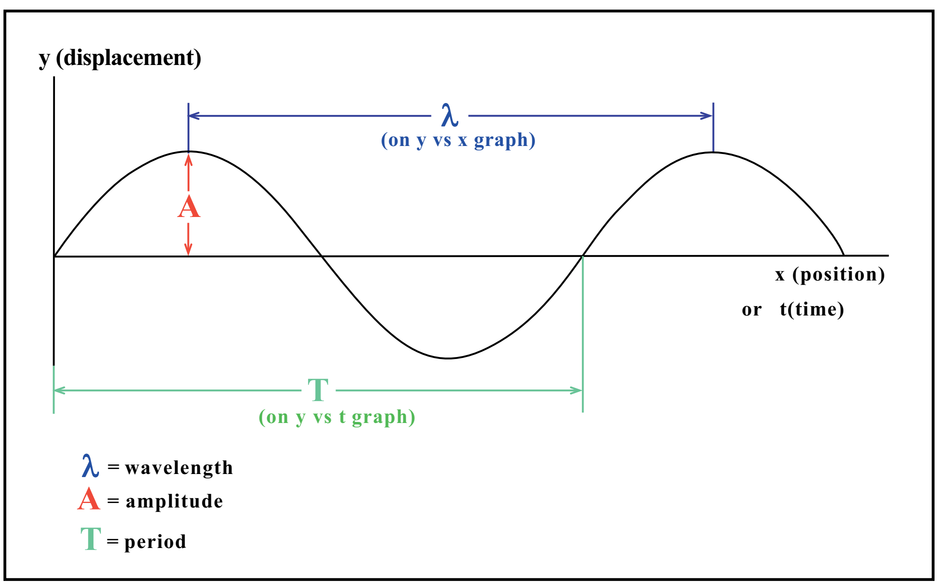

Fig. (2). Basic characteristics of the sinusoid or sinewave.

CHAPTER 3

The Applied Mechanical Vibration as Ultrasound Energy

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Abstract: Ultrasound is a form of mechanical energy transmitted through and into biological tissues as an acoustic pressure wave at frequencies higher than that of the upper limit of human hearing, and it is used widely in medicine as a therapeutic, operative, and diagnostic tool.

Therapeutic US has a frequency range of 0.75-3 MHz, with most machines set at a frequency of 1 or 3 MHz.

Ultrasound can produce many effects other than just the potential heating effect, acting as a mechanotransduction, a complex biological process that involves the spatial and temporal orchestration of numerous cell types, hundreds if not thousands of genes, and the intricate organization of the extracellular matrix. The intensity or power density of the ultrasound can be adjusted depending on the desired effect and the target tissue.

Keywords: Aesthetic applications, Cavitation, Dosimetry, Non-thermal effects, Phonophoresis, Reparative and Regenerative medicine, Thermal effects, Ultrasound.

INTRODUCTION

Methods to generate and detect ultrasound (US) first became available in the United States in the 19th century; however, the first large-scale application of US was for navigation of submarines during World War II. In the SONAR, a short

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pulse of US is sent from a submarine through the water, and a detector picks up the echo of the signal. Sound waves are sent out, they returned to the sender "ping" qualities.

In the 1920s it was also observed that extremely high-pressure waves were damaging to living tissues. As early as the 1930s, low intensities of therapeutic US were used for the first time in physical medicine to treat soft tissue conditions with mild heating. Today therapeutic US is a commonly used modality in therapy clinics, applied for its deep heating ability. However, therapeutic forms of US that are available in the twenty-first century are capable of many more applications than providing just deep heating.

PHYSICAL CHARACTERISTICS OF US

Sound is a vibration that propagates as a mechanical wave from a source to a receiver (for example, the ear), through a medium such as air or water. US consists of a mechanical vibration very similar to sound wave, its frequency is greater than 20 kilohertz (20,000 hertz), which represents the threshold of human hearing [1]. The wave specific feature is that the particles of the medium oscillate around a position of equilibrium, this generates movements of the collision between a particle and the other generating a series of similar reactions. A desk ornament, sometimes called Newton's cradle (Fig. **1**), illustrates some principles of this type of energy transfer. It consists of a frame with five metal balls suspended through wires from a horizontal bar so that they touch each other at rest. If one lifts and releases the first ball, the mobile will set in motion. When the first ball swings back into place it bumps into the next ball, which in turn bumps into the one after it. In this way, the energy is transferred from ball to ball. Because the last ball is unopposed, it swings out into space; however, when it drops back into line, a new cycle is set in motion [2].

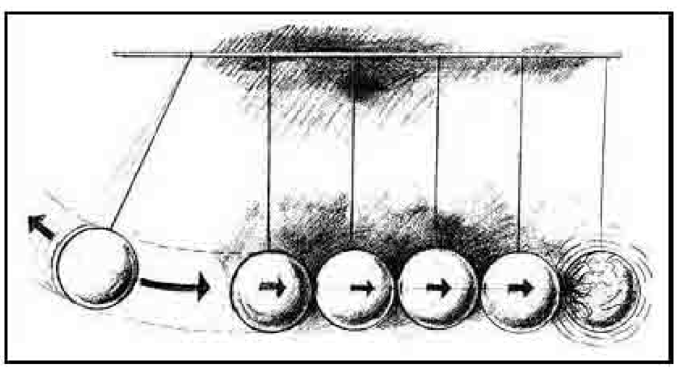

Fig. (1). Newton's cradle. From: http://www.bookvip.net/shock-wave-physics.html.

Waves can travel through media as longitudinal, transverse, and standing waves. When the particles of a medium are compressed and decompressed in the direction that a wave travels, it is termed as longitudinal wave. When particle movement is at right angles to the direction of travel, it is termed as shear or transverse wave (Fig. **2**) [3, 4]. Shear waves propagate or start more readily in solids, and longitudinal waves in liquids and gases.

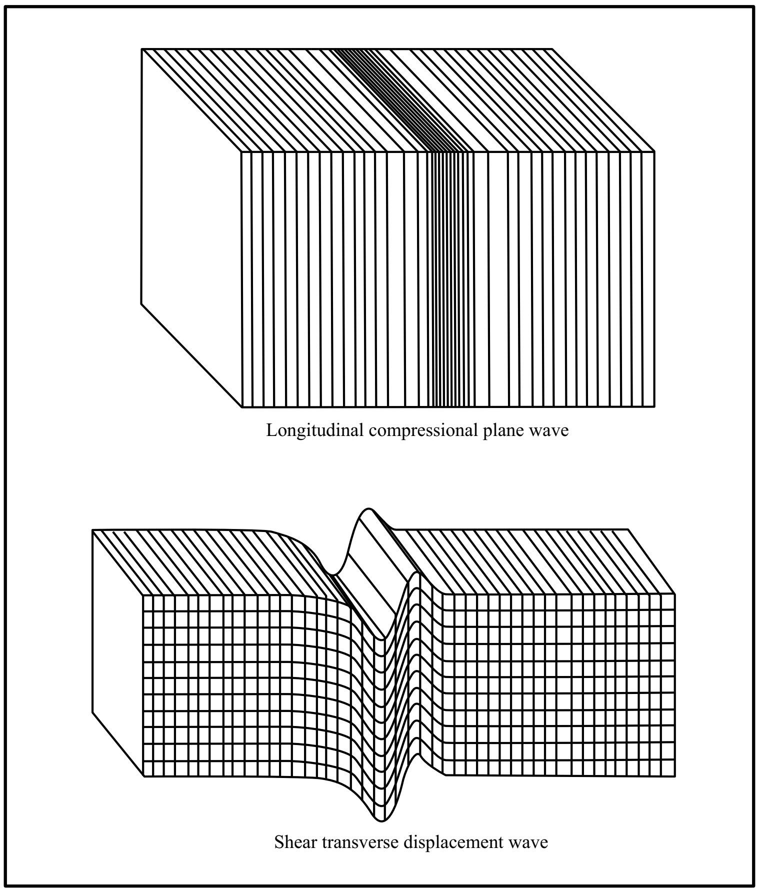

Fig. (2). Two examples of acoustic pulses, travelling from left to right. The media on either side of the wave pulse is in the equilibrium position: that the right of the pulse has not yet been disturbed, and that on the left has returned to equilibrium after the oscillations associated with the pulse have damped down. The depicted waves are the longitudinal (compressional) plane wave and the shear (transverse displacement) plane wave. Modified From: Timothy G. Leighton "What is ultrasound?" Progress in Biophysics and Molecular Biology 93 (2007) 3–83.

US can also be defined by the following physical parameters that characterize the wave:

CHAPTER 4

The Applied Mechanical Vibration as Extracorporeal Shock Wave

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Abstract: After its originary introduction as urological lithotripsy (still clinically applied), shock wave progressively gained a growing therapeutic importance in some different medical fields. Initially restricted in many musculo-skeletal disorders, in more recent years, thanks to a better knowledge about its mechanisms of actions (mainly antiflogistic, angiogenic and analgesic), this particular form of mechanical vibration nowadays represents a real innovative and unexpected therapeutic tool at the service of rehabilitation and regenerative medicine. The effectiveness, safety and ductility of shock wave therapy make it a unique and versatile strategy with further promising therapeutic perspectives in the near future.

Keywords : Focused and unfocused waves, Lithotripsy, Mechanical stimulation, Radial wave, Regenerative processes, Shock wave generators, Shock waves.

INTRODUCTION

Shock waves are a particular form of mechanical stimulation, whose first medical application was limited to the treatment (breaking up) of kidney stones (as extracorporeal shock wave lithotripsy). In the following years, it expanded to the musculo-skeletal field, mainly for the treatment of some tendon and bone diseases, and more recently some other important and revolutionary clinical applications in the field of regenerative medicine have been studied and introduced in clinical practice [1 - 3]. Nowadays, Extracorporeal Shock Waves

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Therapy (ESWT) represent a valid tool for a wide range of disorders, both in orthopedics and rehabilitative medicine (tendon pathologies, bone diseases, vascular bone pathologies), but also in dermatology and vulnology (chronic wounds, ulcers, scars) [4 - 19], neurology complications such us spasticity [20, 21], or some sexual disturbances (*induratio penis plastica* and erectile dysfunctions) [22 - 28], and cardiology (in relation to ischemic heart diseases) [29 - 32].

Based on its noninvasiveness, safety (as absence of main side effects) tolerability, repeatability, and efficacy (if properly applied), extracorporeal shock waves constitutes a unique therapeutic tool in a broad range of medical conditions, representing a very useful medical solution especially when other conservative or surgical treatments are ineffective or failing [33 - 35].

GENERAL CHARACTERISTICS OF SHOCK WAVES

Shock wave (SW) is a particular form of mechanical stimulation, firstly described, as physical entity, at the beginning of the 19th century; only two centuries later, during World War II, based on fortuitous findings, some researchers began to study their possible therapeutic application in humans (other than their technical usage), aimed to exploit their potential for breaking structures. In fact, besides some early experimental attempts for destroying brain tumors in 1960, the main interest was reserved to the fragmentation of kidney stones (urolithiasis), and, at the beginning of the nineties, in Munich, extracorporeal shock wave lithotripsy was applied for the first time [36].

Soon after, in 1991, still based on some occasional observations, it was discovered that, from a simple mechanical stimulation (shock waves), it is possible to induce some relevant medical effects, unexpected before that time, and related to a biological action. Valchanov and Michailov in 1991 described the successful treatment of bone healing disturbances by SW application (that is osteogenesis induction), as the first non-urological application [37]. This should be considered as a milestone in the evolution of SW therapy, that is the changeover from the "mechanical model" of extracorporeal shock wave lithotripsy to its application as "mechanotherapy" on living tissues in all extra urological fields, where mechanical stimulations are applied for therapeutic purposes, based on biological reactions, as described below [38].

Since 1991 until now, SWs rapidly spread as orthotripsy for many musculoskeletal disorders (mainly bone healing diseases and tendon disturbances), although still considered as a relatively "pioneristic therapy" until few years ago, especially as this technique was inherited from urological applications, where it acts as a pure mechanical force. Still having in mind the "mechanical" action of breaking renal stones, at the beginning of the musculoskeletal applications and for some years later, the main interest was addressed toward calcifications disruption. Finally, in the early years of the new millennium, due to the discovery of its regenerative potential, and the increasing number of scientific results published in literature, the efficacy of SW as a biological tool was made clear (not only a pure mechanical one). From a general point of view, it was necessary to wait for some years, since the emergence of their originary successful clinical applications, to know a great deal about the mechanisms of action of SW at the tissue and cellular level, in order to explain many clinical therapeutic results.

SWs are acoustic waves, characterized by a pick pressure rises from the ambient value to its maximum within very few nanoseconds. SWs can be distinguished from some other acoustic waves (as ultrasounds for examples), due to their shape, characterized by initial high peak-pressure amplitude, rapidly followed by a drop to a negative value within few microseconds [39 - 45].

In 1997, the physical characteristics of SWs, used in the therapeutic fields, were established by a Consensus Conference, relative to the parameters recognized by numerous SW Scientific Societies [40] (Fig. **1**):

- rapid rise in pressure (< 10 ns);
- high peak pressure (up to 100 MPa);
- short-time duration (< 1000 ns).

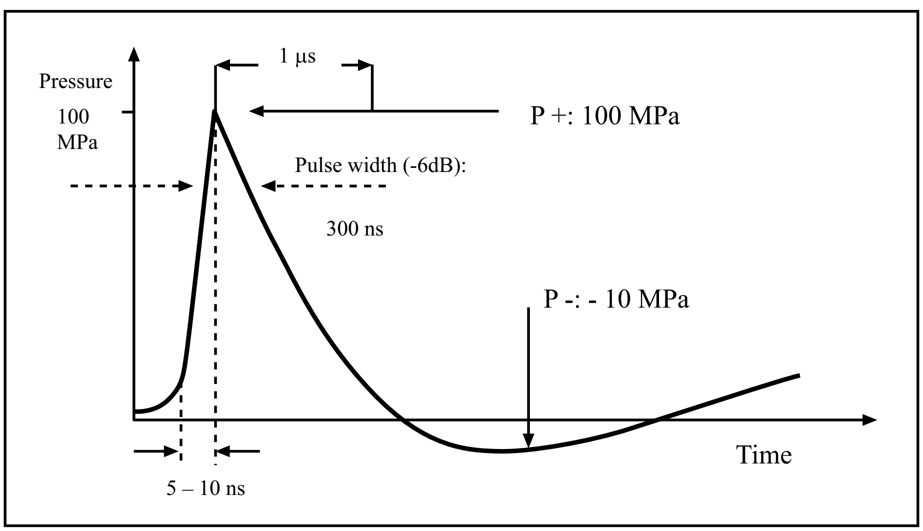

Fig. (1). ESWT: physical characteristics of wave. From: Ogden JA, Tóth-Kischkat A, Schultheiss R. Principles of shock wave therapy. Clin Orthop Relat Res 2001; (387): 8-17.

CHAPTER 5

The Electromagnetic Vibration: Physical Principles and Biomolecular Effects

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Abstract: Life on Earth has evolved in a sea of natural electromagnetic fields. Electromagnetic waves show a biological interaction with living matter, even when they are so weak (as in the case of the so-called long radio waves, which have frequencies lower than 80 kHz) to have non-thermal effects, which seem to be both negative and positive, depending on the frequency and on the coupling with the geomagnetic field.

Many studies report that exposure to man-made electromagnetic fields affects cellular and systemic function and metabolism, with risk for malignancy and pharmacological effects. Hence, the employment of low-frequency electromagnetic fields – especially pulsed electromagnetic fields – seems to be promising, having potential applications in biomedical engineering, biotechnology, biology, oncology, and regenerative medicine.

Keywords: Blackman-Liboff-Zhadin effect, Electromagnetic fields, coherent domains, extremely low frequency, microbiological spectroscopy, pulsed electromagnetic fields, regenerative medicine, thermal and non-thermal effects, tumor-specific frequencies.

INTRODUCTION

Life on earth has evolved in a sea of natural electromagnetic fields (EMF). Like other waveforms, electromagnetic waves also are physically characterized based

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on wavelength (λ) and frequency (ν), that are related through the following relationship:

$$\lambda \cdot \nu = c \qquad \textbf{(1)}$$

Where c is the speed of light (299,792.458 km/s).

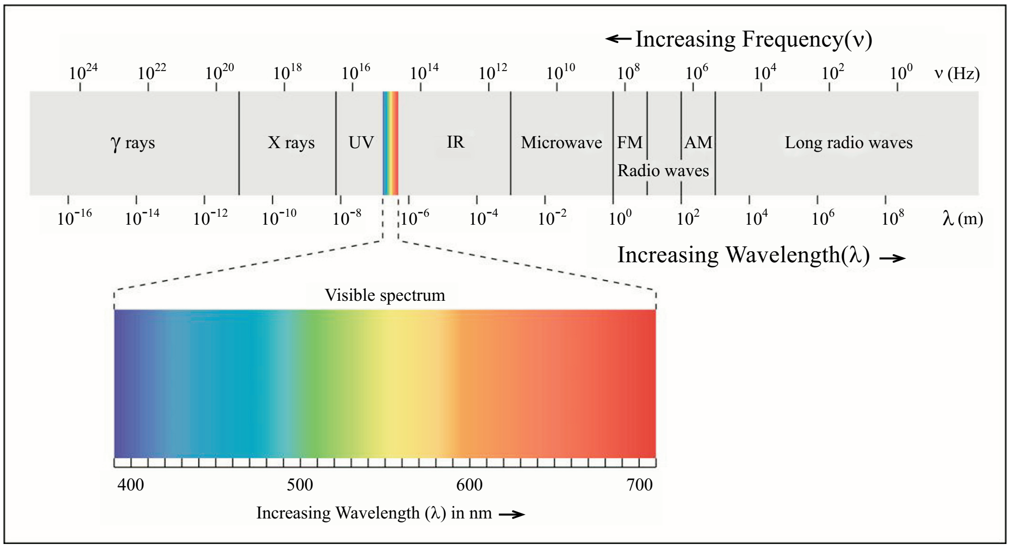

Fig. (1). The electromagnetic spectrum.

The electromagnetic spectrum is very wide and includes phenomena so different such as gamma rays, X-rays, ultraviolet, visible light, infrared, microwave, and radio waves. Gamma rays and X-rays and the more energetic ultraviolet are able to ionize molecules, because their photons transfer an energy to molecules so high to cause the escape of one or more electrons. The other frequencies, of light included, are not so energetic, and cannot ionize molecule in empty space, therefore, they are called non-ionizing radiations (NIR). All waves with frequencies lower than 80 kHz are generically referred as "long radio waves". Properly, this name has to be referred to waves with frequency higher than 3 kHz, employed to communicate by air, while frequencies under such threshold are only used for marine radio-communication between ships and submarines or between submarines. Thus their use cannot only be referred as long radio waves. In the range of frequency under 3 kHz, different bands can be distinguished: the Very Low Frequency (VLF) between 3-30 kHz, the Ultra Low Frequency (ULF) between 300-3000 Hz, the Super Low frequency (SLF) between 30-300 Hz, and Extremely Low Frequency (ELF) below 30 Hz.

THERMAL AND NON-THERMAL EFFECTS OF ELECTROMAGNETIC VIBRATIONS

Electromagnetic vibrations show a biological interaction with living matter, even when they are so weak (as in the case of long radio waves) to be considered non-thermal waves, *i.e.* when they are unable to induce a transfer of thermal energy to the living matter. The expression "non-thermal", referred to waves or to electric or magnetic or electromagnetic fields, is significant only with reference to the nature of the target that is exposed to the wave or the field [1].

Even if NIR are not able to ionize matter in empty space (and then in air, since the speed of light does not change significantly from empty space to air), their intensity can be so high that they become able to transfer thermic energy to living matter inducing several thermal biological effect. The best known thermal effects are burns, sunstrokes, and other shocks due to short term exposures; other possible effects are due to the thermal interaction of electromagnetic fields with animals and humans.

In May 2011, the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) classified the microwaves of wireless telephony as a «possibly carcinogen» (group 2B of the scale of carcinogenicity) [2]. As proposed in the draft of the WHO EMF Project, discussed in the WHO Conference on the precautionary principle in Luxembourg (25-26 February 2003), the possible carcinogenic effect of microwaves on humans should be due to the circumstance that portable devices can generate power in the same order of the limit established in Europe for the exposure of head (2 W/kg) [3], thus in the same order of the thermal threshold established for human exposures, set at 4 W/kg. The thermal threshold is the specific power of the incident wave able to induce an increase of the basal temperature equal to 0.5°C within 12 minutes. Power is the time derivative of energy, thus the amount above is the specific energy rate that is actually absorbed by the exposed human target; such amount is named Specific Absorption Rate (SAR). The thermal threshold is referred to a male with 70 kg weight and 175 cm highness (this standard was established in 1953 by the American Conference of Governmental Industrial Hygienists, based on studies about United States Navy sailors exposed to radar). Above the thermal threshold, the incident wave or field is able to induce an increase of basal temperature as 0.5°C or more; under the threshold it is not able to induce any durable increase of temperature, since after 6 minutes the homeostasis of human body compensate for the thermal absorption, reaching the basal temperature. Furthermore, the power of 4 W has to be the average of the absorbed energy for unit of time and of mass of the whole body of the target, *i.e.* of the exposed man. For the standard man, as above, the absorption of 280 W (J/s) is required to achieve the thermal threshold;

APPENDIX: Update on Therapeutic Applications of Vibrations

Scientific data illustrated in previous chapters and those collected by our personal experience allow us to summarize that each type of vibration has a proper applicability in terms of cost/benefit ratio. It is clear that using vibration therapy on the basis of scientific knowledge we can determine the tissue repair or modulate regeneration. The obtained results in rehabilitation essentially depends on type, extension and location of damaged tissue, type and set parameters of applied mechanical therapy, frequency and duration of treatment.

The best approach to bone damage varies depending on specific conditions:

- fresh fracture
  - 1^{st}-line treatment: focused extracorporeal shock waves
  - 2^{nd}-line treatment: pulsed electromagnetic fields
- delayed bone union, nonunion
  - 1^{st}-line treatment: pulsed electromagnetic fields
  - 2^{nd}-line treatment: focused extracorporeal shock waves

- pseudo arthrosis, osteonecrosis
  - 1^{st}-line treatment: focused extracorporeal shock waves
  - 2^{nd}-line treatment: medium- and low-intensity electromagnetic fields

The best approach to muscle tissue damage depends on the timing of the injury:

- acute muscle injury
  - 1^{st}-line treatment: pulsed electromagnetic fields
  - 2^{nd}-line treatment: low-frequency ultrasounds
  - 3^{rd}-line treatment: *EndoSphères Therapy*®
- chronic muscle injury
  - 1^{st}-line treatment: focused mechano-acoustic vibrations
  - 2^{nd}-line treatment: low-frequency ultrasounds
  - 3^{rd}-line treatment: focused or unfocused extracorporeal shock waves
  - 4^{th}-line treatment: *EndoSphères Therapy*®

To modulate muscle activity it could be applied:

- to reduce muscle tone
  - 1^{st}-line treatment: focused mechano-acoustic vibrations
- to enhance muscle tone
  - 1^{st}-line treatment: focused mechano-acoustic vibrations
  - 2^{nd}-line treatment: whole-body vibrations

The best approach to muscular fascia:

- 1st-line treatment: focused mechano-acoustic vibrations
- 2nd-line treatment: low-frequency ultrasounds
- 3rd-line treatment: *EndoSphères Therapy*®
- 4th-line treatment: unfocused extracorporeal shock waves

The best approach to tendon injury is:

- 1st-line treatment: focused or unfocused extracorporeal shock waves
- 2nd-line treatment: low-frequency ultrasounds

The best approach to acute and chronic skin lesions is low-frequency ultrasounds and unfocused extracorporeal shock waves, respectively (for more details, see below).

TREATMENT PROTOCOLS WITH FOCUSED MECHANO-ACOUSTIC SQUARE WAVEFORM VIBRATION

With regard to the focused mechano-acoustic vibration, some treatment protocols can be schematically summarized as follows (Tables **1**, **2**).

Table 1. Treatment protocols for the use of focal mechanical vibration.

Frequency	Target
30-50 Hz	Muscle relaxation
50 Hz	Delayed onset muscle soreness
80-100 Hz	Improvement of proprioception
100 Hz	Pyramidal spasticity
120 Hz	Muscle relaxation
100-120 Hz	Pain
200 Hz	Strengthening of slow muscle fibers
300 Hz	Strengthening of fast muscle fibers

Table 2. Treatment protocols for the use of focal mechanical vibration in different muscle conditions.

Muscle relaxation	**50-120 Hz for 10 minutes (applied with an handpiece)**	**Treatment of tender points and fatigue**
	120-200 Hz for 10 minutes (applied with an handpiece)	**Treatment of trigger points and taut bands**
Muscle strengthening in sport, upright position	200 Hz for 10 minutes 300 Hz for 10 minutes 120 Hz for 5 minutes (applied with segmental strips)	Strengthening of slow muscle fibers Strengthening of fast muscle fibers Deconditioning

(Table 2) contd.....

Muscle relaxation	**50-120 Hz for 10 minutes (applied with an handpiece)**	**Treatment of tender points and fatigue**
	120-200 Hz for 10 minutes (applied with an handpiece)	**Treatment of trigger points and taut bands**
Muscle strengthening and corticalization	200 Hz for 10 minutes 300 Hz for 10 minutes 120 Hz for 5 minutes (applied with segmental strips)	Working with squats through active work or isometric muscle contraction
Proprioceptive exercise in combination with *Synergy Mat* (Human Tecar® Unibell srl, Calco, Italy)	60-80-100-120-140-160-180-200-220-240-260-280-300 Hz, to increase every 2 minutes (applied with segmental strips)	Mono- and bipedal walking on unstable proprioceptive platforms

A disorder commonly responsible for many cases of chronic musculoskeletal pain is the myofascial pain syndrome, whose diagnosis is missed often. It can cause tenderness, tightness, stiffness, weakness (without atrophy), associated with hypersensitive areas called trigger points. Placed in taut muscle bands, trigger points cause referred pain in characteristic areas for specific muscles, restricted range of motion, and a visible or palpable local twitch response to local stimulation (Fig. **1**). The treatment of trigger points by a focal vibration system with a handpiece frequency of 120 Hz [1, 2] can be direct or start from the surrounding area and coming on it and the area of referred pain.

- *Direct treatment of trigger point*: it places the handpiece directly on the trigger point up to the relaxation of muscle.
- *Treatment of the taut band, of the trigger point, of the referred pain area*: it highlights the trigger point, the taut band and the referred pain area. It proceeds to treat taut band to 5cm in diameter area from the periphery and towards centripetal to the point of maximum tenderness, continuing the treatment area of referred pain.

Since following the application of a vibration stimulus, bone reacts changing its micro-architecture, at the same time, a balance training with focused mechano-acoustic vibration applied with segmental strips can reduce the likelihood of falling, and hence the risk of fall-related fractures (Fig. **2**), we adopt the following protocol to treat osteoporosis/osteopenia and prevent falls (Table **3**).

Integrated protocols involve the use of focal vibrations in combination with active exercises and systems that increase proprioceptive stimulation to determine the synergy between stimuli. For example, we work with *Synergy Viss*® (Synergy Viss Human Tecar® Unibell srl, Calco, Italy) to carry out eccentric exercises in upright position on Bosu ball, a half-spher--shaped unstable platform, composed of a hard and a rubber hemispherical platform (Fig. **3**).

Another type of integrated protocol used both in sports for functional recovery after muscle injury and in neurological diseases for the recovery of kinetic and kinematic characteristics of gait, as well as in developmental disorders and functional decline in the elders includes the use of *Synergy Viss*® (Synergy Viss Human Tecar® Unibell srl, Calco, Italy) with a proprioceptive system called *Synergy Mat*.

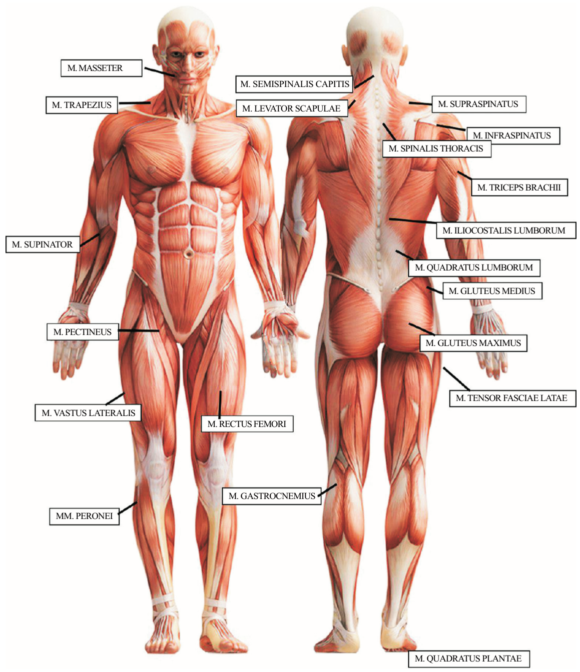

Fig. (1). Common trigger points.

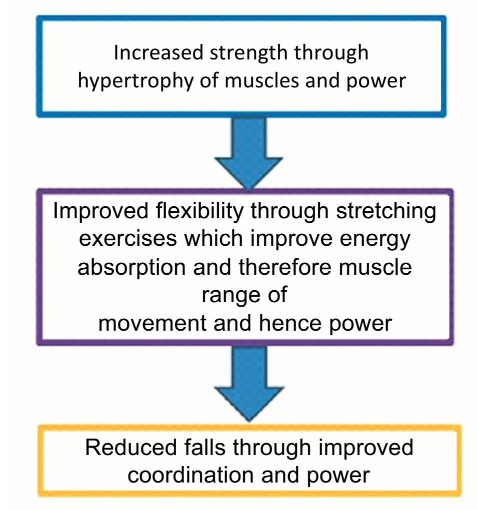

Fig. (2). Treatment goals.

Table 3. Treatment protocols for the use of focal mechanical vibration in osteoporosis/osteopenia and prevention of falls.

Sites of application	trapezius muscle (upper fibers) triceps brachii muscle latissimus dorsi muscle quadratus lumborum muscle rectus abdominis muscle	gluteus maximus muscle rectus femoris muscle biceps femoris muscle tibialis anterior muscle
Treatment parameters	*Wave frequency*: 200-300 Hz *Maximum wave pressure*: 500 mbar	
Duration and number of sessions	10 minutes per session, twice a week, for at least 6 months	

Fig. (3). *Synergy Viss* ® (Synergy Viss Human Tecar® Unibell srl, Calco, Italy) to carry out eccentric exercises in upright position on Bosu ball.

Synergy Mat (Human Tecar® Unibell srl, Calco, Italy) is the innovative response to these needs of training, rehabilitation and natural and harmonious reeducation of the body. Different surfaces give the possibility to work barefoot on routs instability with different levels, responding to the needs of personalized training and rehabilitation. Different densities correspond to different level of movement absorption, providing protection of the joints and increasing time the energy expenditure. The variety of interchangeable elements that composed the *Synergy Mat* set (mats and pillows) provides many combinations of routes adapted to the user specific needs (Fig. **4**).

Fig. (4). Integrated protocol with *Synergy Viss® (Synergy Viss Human Tecar® Unibell srl, Calco, Italy)* and proprioceptive system- *Synergy Mat*.

TREATMENT PROTOCOLS WITH WHOLE-BODY VIBRATION

The following guidelines were developed over several years of clinical experience.

First of all the familiarization with the training whole-body vibration can be achieved in approximately 1 min with slow (5-12 Hz), subjectively comfortable frequency and middle amplitude of "swing" (where the subjective feeling of comfort is individual and varies significantly) (Table **4**, Fig. **5**).

Table 4. Guidelines for the use of whole-body vibration.

Stretching	*Frequency*: 10-18 Hz, subjectively comfortable "swing frequency" (varies with the individual's posture and hence resonance frequency). *Duration*: slowly attain the end position until a significant stretching can be felt; maintain this position for 10-30 s and then return to the starting position. Two or three repetitions. Repeat each exercise for 1 or 2 minutes.	Improvement of elasticity and joint range of motion. Stretching should be incorporated into the commencement of each training session so as to optimize the muscle elasticity.
Balance	*Frequency*: 5-12 Hz, the lower the frequency, the harder the exercise (varies with the individual client and posture). *Duration*: every exercise should be undertaken for 1 or 2 minutes, several repetitions of each exercise are possible, several times per day.	Improvement of stability.
Force	*Frequency*: 25-40 Hz (varies with the training device). *Duration*: To the point of fatigue of the musculature.	Improvement of muscle strength and muscle mass.

Fig. (5). Example of exercises on whole-body vibration platform.

Application of Whole-body Vibration Therapy in the Treatment of Osteoporosis/Osteopenia

Exercises on whole-body vibrating plates for osteoporosis/osteopenia should be conducted over a longer period (at least 6 months) and never conducted if the subject is experiencing pain. Strength training should be individually selected depending on the concept of progressive training. A training session should last 15-20 minutes, divided into series of 60 seconds with 60-second rest between each series. Within 6 months, two or three training sessions per week should be undertaken, with at least 1 rest day for recovery between training sessions (Table **5**).

Table 5. Treatment sequence for the use of whole-body vibration in osteoporosis/osteopenia.

First session	*Frequency*: 5-12 Hz. *Duration*: 1-3 minutes.	Standing with slightly bent knees. If possible without holding on. The vibration can be directed to various body parts through changes in the center of gravity and slowly straightening the knees. Stretching exercises out of the stretching and balance series.
Protocols	*Frequency*: 15-30 Hz. *Duration*: 3-5 minutes for each exercise.	Exercises varying between the force and power series. Also some of the exercises from the balance series may be appropriate. 1 or 2 applications per series, without rest. 1-to-2-minute rest between the applications.
Relaxing	*Frequency*: 5-10 Hz. *Duration*: 1-2 minutes.	Relaxed, moving the body gently forwards and backwards with slightly bent knees while not holding on. The soles of the feet must stay fully on the vibration plate.

Application of Whole-body Vibration Therapy in Reducing the Likelihood of Falling

The duration of treatment in subjects who are at risk of falling varies between individuals. In order to maintain/sustain mobility and power the training in these individuals should become daily routine. Progression occurs with increasing strength of the client. Divide training into sets and repetitions. At least 48 hours rest between exercise sessions are required. Balance training can be carried out several times per day (Table **6**). Power training is attained through all series since power = force • velocity, which is a combination of coordination, balance and strength. Muscle power is essential to prevent falls. A reaction within milliseconds can reduce the risk of falling.

Application of Whole-body Vibration Therapy in Low Back Pain

The aim of the treatment is to improve the elasticity of paraspinal muscles, and hence the range of motion of the trunk (Table **7**).

Application of Whole-body Vibration Therapy in Weighted Dumbbell Training

Vibration dumbbell systems are less commonly used than the vibration platforms. Vibration dumbbells can be adjusted from 5 to 40 Hz with amplitude of approximately 2.0 mm. From the reflex-provoked muscle contraction arises an increase in strength and power, depending upon the training parameters. Improved inter- and intramuscular coordination occurs due to the nature of the cyclical and fast stimulation. The aim of the oscillatory dumbbells is improved strength of the shoulder and elbow muscles. In a sitting or standing position, grab the dumbbells with both hands with some light pre-tension. The starting position varies depending on pathology. If necessary, the elbow can be flexed and supported on a table (Table **8**).

Table 6. Treatment sequence for the use of whole-body vibration in prevention of falls.

Strength training	*Frequency*: 15-12 Hz. *Duration*: 3-5 minutes. *Amplitude*: medium to high, depending on comfort.	Starting position: exercises out of force and power series alternately. Sets of 10, 3 sets per exercise. 10-to-20-second rest between sets. 1-to-3-minute rest between the sets. Additional weights 70% of individual's maximal strength.
Stretching / balance exercises	*Frequency*: 15-30 Hz. *Duration*: 3-5 minutes for each exercise. *Amplitude*: low to medium.	Starting position: in standing, carry out exercises from balance and stretching series. The number of repetitions is individually tailored. Importantly, the whole body is gradually brought to an end-of-range stretching position. Balance: placing one foot alternately on the lowest position, slightly lift the other foot and hold at 5 Hz without support for 5-30 seconds.
Power training	*Frequency*: 18-30 Hz. *Duration*: 5-6 minutes. *Amplitude*: medium to high.	Carry out exercises without weights, concentrating on speed and changes in direction.

Table 7. Treatment sequence for the use of whole-body vibration in low back pain.

Stretching exercise	*Frequency*: 5-12 Hz. *Duration*: 3-10 minutes.	Standing, ideally not holding on. Bend the knees slightly. Direct vibration into the various body parts. Then bend the torso forwards, backwards, sideways and into rotation. Ideally, maintain the position at the end of range for 3-5 seconds.
Force and power training	*Frequency*: 15-30 Hz. *Duration*: 3-5 minutes for each exercise.	Exercises out of force and power series alternately. In principle exercise examples from balance-series could also be incorporated here.

(Table 7) contd.....

Post-training relaxation	*Frequency*: 5-10 Hz. *Duration*: 1-2 minutes.	Loose, with slightly bent knees and without holding on, move the whole body slightly. Importantly, the soles of the feet must remain completely on the vibration platform.

Table 8. Weighted dumbbell training.

First session	*Frequency*: 5-15 Hz. *Duration*: 1-2 minutes.	Starting position: individually selected. Arm movements: grab the dumbbells completely and move the arms in various directions. Similarly, move the neck and shoulders in various directions.
Strength training	*Frequency*: 18-40 Hz. *Duration*: 15-30 minutes, with 60-second rest each 120 seconds.	Position: weighted pulleys can also be used. The starting position is always individually attained through the examination process. Repetitions: from2 to 10 repetitions with a 1-minute rest between repetitions. Sets: 2-5 sets with a 3-to-5-minute rest between sets.
Relaxing	*Frequency*: 5-10 Hz. *Duration*: 1-2 minutes.	Relaxed, moving the body gently forwards and backwards with slightly bent knees while not holding on. The soles of the feet must stay fully on the vibration plate.

TREATMENT PROTOCOLS WITH ULTRASOUNDS

Ultrasounds (US) can be delivered in continuous or pulsed mode. In the *continuous mode* the US wave has a constant amplitude, whereas in the *pulsed wave* the pressure amplitude is not constant and is zero for part of the time. In the latter mode, no acoustic energy is being emitted between pulses and the US propagates through the medium as small packages of acoustic energy. Pulsed waves can have any combination of “on”/“off” times. Thus, it is important to specify exactly the time regimen of the pulsed beam. The percentage of “on” time of US output is known as the “duty factor/cycle”, which can be expressed as a percentage or as a ratio. Clearly, when output is continuous, the duty factor is 100%; the output must have an “off” time for it to be considered pulsed.

In literature, the use of US in the field of rehabilitation seems to play a minor role (Table **9**); in our experience, we use US as part of integrated protocols among others physical therapies.

Table 9. Summary of US clinical protocols.

Location and condition		***Treatment parameters***		
		frequency (MHz)	***duty cycle (%)***	***duration (minutes)***
Superficial muscle and/or tendon and/or ligament	subchronic injury	3.3	20	5-7
	chronic injury	3.3	100	5-7
	tissue scar or adhesion	3.3	100	5-7

(Table 9) contd.....

Location and condition		***Treatment parameters***		
		frequency (MHz)	***duty cycle (%)***	***duration (minutes)***
Deep muscle, tendon and/or ligament	subchronic injury	1	20	7-10
	chronic injury	1	100	7-10
	tissue scar or adhesion	1	100	7-10
Joint contracture and/or adhesive capsulitis	superficial joint	3.3	100	5-7
	deep joint	1	100	7-10

In recent years we experienced the use of continuous low-frequency US shock thermic LF Esasound (Table **10**) and of pulsed low-frequency US for the integrated treatment of soft tissue injuries with the following protocols (Table **11**).

Table 10. Therapeutic protocols with the use low-frequency US shock thermic (LF Esasound).

Condition	***Treatment parameters***		
	frequency (MHz)	***duty cycle (%)***	***duration (minutes)***
Low back pain	38	90-100	3-5
Myofascial pain	34	90-100	3-5
Muscular contracture	38	90-100	3-5
Muscular fibrosis	38	90-100	3-5
Edema	38	90-100	3-5
Lymphostasis	30	90-100	3-5
Localized fat deposit	38	90-100	3-5
Scar	30	90-100	3-5

Table 11. Therapeutic protocols with the use low-frequency US.

Condition	***Treatment parameters***		
	frequency (MHz)	***duty cycle (%)***	***duration (minutes)***
Low back pain	40	40-80	15
Myofascial pain	42	40-80	20
Muscular contracture	38	33-75	20 or 30
Muscular fibrosis	38	33-75	30

(Table 11) contd.....

Condition	***Treatment parameters***		
	frequency (MHz)	***duty cycle (%)***	***duration (minutes)***
Edema	42	40-80	15
Lymphostasis	15	50-80	20
Localized fat deposit	15	50-80	30
Scar	38	33-75	5

TREATMENT PROTOCOLS WITH EXTRACORPOREAL SHOCK WAVES

Extracorporeal Shock Waves (ESW) has been widely recognized in literature as a biological regulator on bone, ligament, tendon and muscle tissue. In musculo- skeletal disorders, ESW has been primarily used in the treatment of bone defects (delayed fracture healing, bone nonunion, avascular necrosis of femoral head) and tendinopathies (proximal plantar fasciopathy, lateral elbow tendinopathy, calcific tendinopathy of the shoulder, and patellar tendinopathy). Nowadays, ESW therapy represents a valid tool for a wide range of disorders, both in orthopedics and rehabilitative medicine (tendon pathologies, bone healing disturbances, vascular bone diseases), dermatology and vulnology (wound healing disturbances, ulcers, painful scars) and neurology (spastic hypertonia and related disturbances).

ESW can be generated by electrohydraulic, electromagnetic or piezoelectric methods. The focused shock waves concentrate acoustic energy in a well-defined point, or focal area. The physical parameters that influence treatment response are summarized in the following Table **12**.

Table 12. Therapeutic parameters of ESW therapy.

Treatment parameter	**Description**
Maximal positive pressure	The maximal positive pressure that is reached
Focal zone	A three-dimensional ellipsoid where the pressure is above a certain value
Energy flux density	The amount of energy per surface unit (expressed in mJ/mm^2)
Impulse frequency	The number of shock waves that is applied per second

The energy level is commonly categorized into three groups depending on the energy flux density [3] (Fig. **6**):

- low-energy ESW, with an energy flux density below 0.08 mJ/mm^2 ;
- medium-energy ESW, with an energy flux density from 0.08 to 0.28 mJ/mm^2;
- high-energy ESW, with an energy flux density from 0.28 to 0.60 mJ/mm^2.

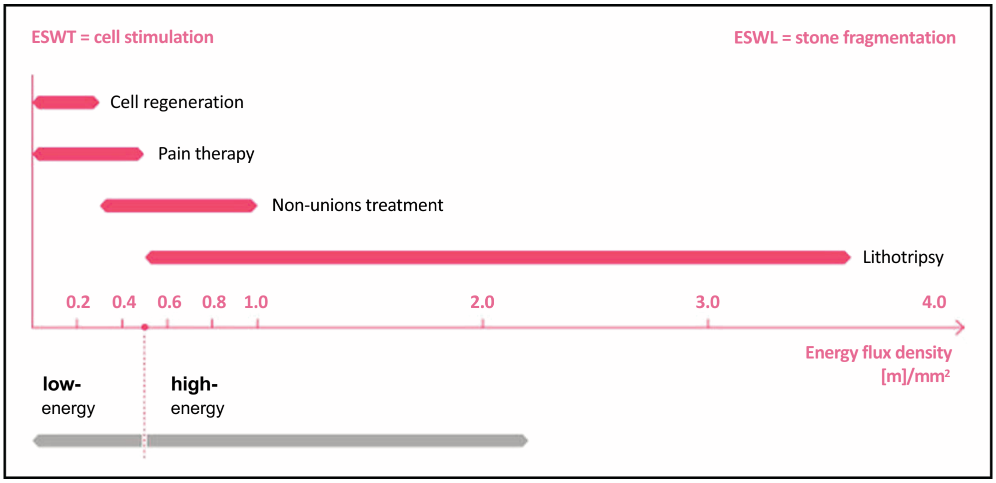

Fig. (6). Fields of application and relative energy levels of shock waves in medicine. ESWL, Extracorporeal Shock Waves Lithotripsy; ESWT, Extracorporeal Shock Waves Therapy.

ESW treatment protocols have not yet been standardized, with significant diversity between the studies in dosages, frequency of applications, density of energy and total energy applied. Other variations in technique include the treatment site and use of anaesthetic injections prior to shock wave application. The lack of standardized protocols in the use of shock waves comes from the variety of devices used, the parameters for the application, the application times that do not allow the comparison between the various studies. Our expertise in the use of shock waves is long lasting and it is the result of clinical practice and research [4 - 7].

From 1998, in our rehabilitation Center we utilize focused ESW generated by an electro-hydraulical source; from 2009 with *Orthogold 100*® (MTS Medical UG, Konstanz, Germany) (Fig. **7**).

Electrohydraulic systems incorporate an electrode, submerged in a water-filled housing composed of an ellipsoid and a patient interface. The electrohydraulic generator initiates the shock wave by an electrical spark produced between the tips of the electrode. Vaporization of the water molecules between the tips of the

electrode produce an explosion, thus creating a spherical shock wave. The wave is then reflected from the inside wall of a metal ellipsoid to create a focal point of shock wave energy in the target tissue. The size and shape of the ellipsoid control the focal size and the amount of energy within the target. Each operator aims to couple the generated pressure pulse to the tissue while minimizing energy loss, concentrating the shock waves so that they can be applied in sufficient quantity to stimulate a desired tissue response. For their clinical use, the head of the shock-wave generators are positioned over the area to be treated, which can be determined on the basis of previous diagnostic images or, if available on the device, by radiographic or US positioning systems. Once the position of the targeting site has been located, the treatment area is prepared with a coupling gel to minimize the loss of shock wave energy at the interface between the head of the device and the skin. The characteristics of the device are the following:

- applicator OE35
  - therapeutic focus (-6dB): 0-79 mm
  - energy flux density: 0.01- 0.16 mJ/mm^2
  - focus energy (E total / -6 dB): 0.34-4.22 mJ
- applicator OE50
  - therapeutic focus (- 6dB): 0-62 mm
  - energy flux density: 0.03- 0.27 mJ/mm^2
  - focus energy (E total / -6 dB): 0.3-6.15 mJ
- dimensions: 21.8 x 40 x 45.9 cm
- power supply: alternating current 100-240 V, 50- 60 Hz
- power input: 200 VA
- repetition rate: 0.5-8 Hz

Fig. (7). *Orthogold 100*® (MTS Medical UG, Konstanz, Germany).

ESW in Bone Disorders

Several studies investigated the effects of ESW on acute fracture healing, delayed fracture healing, bone nonunion, and avascular necrosis. Experimental models demonstrate that ESW promotes bone healing through a biological response characterized by the upregulation of local expression of angiogenesis-related growth factors, endothelial nitric oxide synthase, and vascular endothelial growth factor, as well as bone growth factors and morphogenetic proteins. Table **13** summarizes our treatment protocols for bone diseases.

ESW in Tendinopathies

Though supported by clinical data, the validity, effectiveness and reliability of ESW in the treatment of tendinopathies do not always meet the criteria of evidence-based medicine. This is mainly due to an objective difficulty in comparing data from non-homogeneous studies, which have adopted various types of ESW generators, with differing energy parameters and treatment protocols. Nonetheless, the most frequent application of ESW is in the treatment of tendinopathies. Our treatment protocols for tendinopathies are summarized in Table **14**.

Table 13. Treatment protocols for bone diseases with *Orthogold 100*® (MTS Medical UG, Konstanz, Germany).

Condition	Energy flux density	Number of impulses per treatment	Repetition rate	Number of treatment sessions
Non-union, delayed union	0.10-0.17 mJ/mm^2	600-800	6 Hz	1 per week for 4-6 weeks
Stress fracture	0.12-0.19 mJ/mm^2	400 + 400	6 Hz	2 per week for 3-5 weeks
Avascular necrosis	0.14-0.21 mJ/mm^2	700-800	6 Hz	1 per week for 4-6 weeks
Bone marrow edema	0.10-0.21 mJ/mm^2	350 + 350	6 Hz	2 per week for 3-4 weeks

Table 14. Treatment protocols for tendinopathies with *Orthogold 100*® (MTS Medical UG, Konstanz, Germany).

Condition	Energy flux density	Number of impulses per treatment	Repetition rate	Number of treatment sessions
Calcific tendinopathy of the shoulder	0.17-0.23 mJ/mm^2	600-700	6 Hz	1 per week for 3-5 weeks
Tendonitis of the rotator cuff	0.14-0.21 mJ/mm^2	600-800	6 Hz	1 per week for 3-4 weeks
Lateral epicondylitis	0.12-0.19 mJ/mm^2	600-700	6 Hz	1 per week for 3-4 weeks
Plantar fasciitis	0.15-0.21 mJ/mm^2	600-700	6 Hz	1 per week for 4-5 weeks

ESWT in Skin Pathologies

First investigations on the effect of ESW on wound healing were undertaken in 1986. However, systematic studies (experimental *in vitro* and *in vivo* studies and clinical trials) evaluating the efficacy of low-energy defocused ESW therapy on delayed healing or chronic wounds have only been performed in recent years. Nowadays, ESWT has become increasingly popular and it become accepted in scientific world. Successful application has been reported in the peer-reviewed literature for numerous medical indications. Despite this encouraging progress, the biomolecular mechanisms by which shock waves exert their positive clinical effects are yet to be completely understood. Advantages of ESW include: (1) non-invasiveness (avoidance of surgery); (2) low associated complication rates (*e.g.*, minimal petechial skin hemorrhage and hematoma); (3) efficacy for indications refractory to other standards of practice (*e.g.*, bone nonunion); (4) flat learning curve; and (5) cost-effectiveness.

Possible treatment of pathologic, retracting scars currently includes several options, such as intralesional corticosteroids, cryotherapy, dermabrasion, excision and scar revision surgery, laser therapy and radiation therapy; likewise, prophylactic strategies may include variable combinations of compression therapy, silicone gel and oral supplements such as flavonoids. Nonetheless, retractive scarring is characterized by a complex etiology related to both local and systemic factors, and the efficacy rate of available treatments is still far from satisfactory. As a consequence, treatment of pathologic scars often requires lengthy and expensive procedures, posing the need for clinical studies aimed at the development of novel therapeutic strategies for pathologic scarring. Saggini *et al.* support the role of ESW as an emerging option for the treatment of painful, retracting scars [8]; administration of ESW appears to result in significant improvements in scar clinical appearance, hand mobility and subjective pain.

In the cited studies chronic ulcer and retracting scars of skin were treated with unfocused ESWT probe with electrohydraulical ESW system *Dermagold 100*® (MTS Medical UG, Konstanz, Germany) (Fig. **8**).

Fig. (8). *Dermagold 100*® (MTS Medical UG, Konstanz, Germany).

The characteristics of the device are the following:

- applicator OP155
- therapeutic Focus (-6dB): 0-82 mm
- energy flux density: 0.01-0.19 mJ/mm^2
- focus energy (E total / -6dB): 0.40- 3.88 mJ
- dimensions: 21.8 x 40 x 45.9 cm
- power supply: alternating current 100- 240 V, 50-60 Hz
- power input: 200 VA
- repetition rate: 0.5-8 Hz

Our treatment protocols for chronic ulcers of skin are summarized in Table **15**.

Table 15. Treatment protocols for chronic ulcers of the skin and retracting scars with *Dermagold 100*® (MTS Medical UG, Konstanz, Germany).

Condition	Energy flux density	Number of impulses per treatment	Repetition rate	Number of treatment sessions
Chronic ulcer	0.09-0.11 mJ/mm^2	300-500	4-6 Hz	2 per week for 5 weeks
Retracting scar	0.10-0.13 mJ/mm^2	500-600	4-6 Hz	2 per week for 4-5 weeks

CONFLICT OF INTEREST

The authors confirm that they have no conflict of interest to declare for this publication.

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