

Mechanical Vibration in Rehabilitation: State of the Art

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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 transduction 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.

The purpose of this brief review is to give an overview on the state of the art about the mechanical vibration in physical medicine and rehabilitation.

Keywords: Mechanical vibration; Mechano-acoustic; Focal vibration; Physical therapy; Rehabilitation; Protocols for 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 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].

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.

Background: History of Vibration Up to Now

The first studies on vibrations in medicine dates back to 1880s when the French neurologist Jean-Martin Charcot observed that patients suffering from Parkinson's disease experienced a reduction in their rest tremor and a better sleep after a train carriage ride or after horseback riding. Thus he fashioned a vibratory chair (fauteuil trépidant) that simulated the rhythmic shaking of a carriage and where he replicated the experience seating patient for 30-minute daily sessions [2].

Prolonged observations on Whole Body Vibration (WBV) seem to demonstrate that the vibration-induced muscle mechanical activation could lead to a modulation of the spinal reflex excitability [3] through short spindle-motoneuron connections [4]. In general, it is controversial whether in addition to reflex (involuntary) muscle work there is a mechanism of central (voluntary) control [5]. Furthermore,

vibration appears to be much more specific than cutaneous electrical stimulation, having opposite rather than graded effects on the vibrated and non-vibrated muscle. It has been also demonstrated that vibrations of certain frequency, magnitude, duration and direction are able to ensure that the mechanoreceptors generate action potentials of the same frequency of the applied stimulation (driving phenomenon) [6,7]; a repeated stimulation by means of evoked action potentials of defined frequency is able to selectively recruit precise nerve networks, according to a long-term (months) potentiation phenomenon.

Mechanoreceptors are found in various types of tissue, as skin (Meissner and Pacinian corpuscles), muscles (muscle spindles), tendons, ligaments, articular capsules, periosteum, blood vessels. Vibration of frequency between 20-40 Hz are detected by Meissner corpuscles [8], stimuli of frequency above 60 Hz are detected by Pacinian corpuscles, which have the highest sensitivity (1 mm) at a frequency of 250-300 Hz, thus representing the vibration receptors for excellence [9].

The acoustic wave assumes not a sinusoidal periodic waveform, but a square one in which the amplitude alternates at a steady frequency between fixed minimum and maximum values, with the same duration and an ideally instantaneous transition at minimum and maximum. This allows to reach the maximum wave amplitude instantly and to maintain it on constant values, as well as to stimulate the mechanoreceptors in a continuous manner throughout the duration of the maximum.

The analgesic effect of vibration is attributed to influencing the "gate control" theory of pain. According to this theory, the stimulation of the A β afferent fibers causes the inhibition of the nociceptive fibers by the activation of the inhibitory interneurons in the lamina II (substantia gelatinosa) of the spinal cord dorsal horn [10].

Within the broad range of frequencies available by means of the currently marketed focal vibration devices, several major effects can be distinguished depending on the selected frequency: muscle relaxation around 50 Hz, inhibition of spasticity at 100 Hz, pain relief at 200 Hz, muscle training up to 300 Hz [11].

Clinical Studies and Applications

Currently available WBV exercise devices deliver vibrations at a range of frequencies from 15 to 60 Hz and displacements from <1 mm to 10 mm; the acceleration delivered can reach 15 g. Considering the numerous combinations of amplitudes and frequencies possible with current technology, it is clear that there are a wide variety of WBV protocols that could be used on humans [12]. Studies with the most significant results utilizes frequencies between 25-45 Hz and accelerations of 0.3 g [13-23]; are recommended, furthermore, cycles of short duration (2-20 minutes), interspersed in variable-duration periods of rest [24], and the assumption of an upright posture with hips and knees in modest flexion, to ensure better transmissibility of the forces at the hip and spine [25].

Pistone et al. demonstrated that adding 4-weeks of WBV-OF (Optimal Frequency) to a traditional rehabilitation programme 1 month after anterior cruciate ligament reconstruction surgery is effective in improving muscle strength of the knee flexor muscles; the median value of Optimal Vibration Frequency was 35 Hz (interquartile range 30–45 Hz) [26]. A systematic review conducted by Luo et al. established that WBV is beneficial for enhancing maximal isometric knee extensor strength, but it has no overall treatment effect on BMD, bone turnover markers, anthropometric parameters, or maximal isotonic knee extensor strength in women with postmenopausal osteoporosis [27]. Wei et al. tried to determine the optimal combination of frequency and exposure time of a WBV training program to improve muscle performance of older people with age-related muscle loss. They divided patients into four equal groups, namely, low-frequency long duration (20 Hz × 720 s), medium-frequency medium duration (40 Hz × 360 s), high-frequency short duration (60 Hz × 240 s) and control (no training). The combination of 40 Hz and 360 s of WBV exercise had the best outcome among all other combinations tested and the improvements in knee extension performance can be maintained for 12 weeks after cessation of WBV training [28]. Furthermore pilot studies were performed in twelve patients affected by multiple sclerosis. In the intervention group a whole-body vibration at low frequency (2.0-4.4 Hz oscillations at 3-mm amplitude) in five series of 1 min each (with a 1-min break between the series) was applied. The results indicated that WBV may positively influence the postural control and mobility in multiple sclerosis patients [29].

There are many studies in literature about WBV efficacy and its various fields of application, but the limit of this method is the need to work with a low range of frequencies (15-60 Hz), because of the possible traumatic adverse effects. Instead, with focal mechano-acoustic vibrations, there is the possibility to reach frequencies above 300 Hz, with the possibility to stimulate all the mechanoreceptors. Alongside these benefits, it is of course the ability to modulate wave transmission in various and more specific sites, thanks to the focal applicators.

Using low-frequency focal vibration, the muscle relaxation effect is unique in rate and effectiveness of interrupting the “pain-contracture-pain” vicious circle. In an experimental rehabilitation protocol, Saggini

et al. have identified that a local 90-Hz vibration treatment versus infiltrative therapy with lidocaine is safe and effective in myofascial syndrome of the upper trapezius muscle. In patients receiving vibration therapy there was a significant improvement in pain and muscle elasticity, tone and stiffness, which remained constant at follow-up, whereas patients treated with lidocaine infiltration showed a significant improvement of the stiffness at follow-up. This highlights that vibrations are a valid therapeutic tool to treat musculoskeletal pain and that a protocol of at least 8 weeks lets achieve a therapeutic outcome more efficiently and with a lower onset of pain in patients [30,31].

Otherwise, using high-frequency focal vibration, the same authors reached the normalization of the basal tone in two heads of the quadriceps femoris muscle (rectus femoris and vastus medialis) in ten sporting subjects [32].

In another study, sarcopenic thigh muscles submitted to local vibrational training at 300 Hz for 12 weeks, starting with a session of 15 min stimulation once a week and increasing to three sessions of 15 min per week, displayed enhanced maximal isometric strength and increased content of fast MyHC-2X myosin, without any change in cross-sectional area or in specific tension; analysis of transcriptional profiles by microarray revealed changes in gene expression after 12 weeks of local vibrational training, in particular pathways related with energy metabolism, sarcomeric protein balance and oxidative stress response were affected: thus, course of action of vibration is based on cellular and molecular changes which do not include increase in fiber or muscle size [33], but affects serum level of growth hormone, creatine phosphokinase (increase) and cortisol (decrease) [34].

Using the focused mechano-acoustic vibration at 300 Hz, it has been also shown that a 12-week training is equivalent to a global sensorimotor and a resistance training (60-80% of maximum theoretical force, 10-12 repetitions for 3 sets, 2 sessions per week) in improving balance, with a reduction of sway area and ellipse surface, and in increasing the length of half-step and reducing the width of the support at the gait analysis, with reduction of the risk of falls in the sarcopenic elderly subjects enrolled in the study [35].

With regard to the focused mechano-acoustic vibration, some treatment protocols based on current literature and our experience can be schematically summarized as in Tables 1 and 2 [36].

A disorder commonly responsible for many cases of chronic musculoskeletal pain is the myofascial pain syndrome, whose diagnosis is often missed. 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. The treatment of trigger points by a focal vibration system with a hand piece frequency of 120 Hz [30,31] 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 hand piece 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 5 cm in diameter area from the periphery and towards centripetal to the point of maximum tenderness, continuing the treatment area of referred pain.

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

Protocols	Frequency and Duration	Aims
Muscle relaxation	50-120 Hz for 10 minutes (applied with an hand piece)	Treatment of tender points and fatigue
	120-200 Hz for 10 minutes (applied with an hand piece)	Treatment of trigger points and taut bands
Muscle strengthening in sport, upright position	200 Hz for 10 minutes	Strengthening of slow muscle fibers
	300 Hz for 10 minutes	Strengthening of fast muscle fibers
	120 Hz for 5 minutes (applied with segmental strips)	Decontracting
Muscle strengthening and corticalization	200 Hz for 10 minutes	Working with squats through active work or isometric muscle contraction
	300 Hz for 10 minutes	
	120 Hz for 5 minutes (applied with segmental strips)	
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

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

With the application of a vibration stimulus bone reacts changing its microarchitecture; at the same time a balance training with focused mechano-acoustic vibration, applied with segmental strips, can improve muscle strength. Therefore it is possible to reduce the likelihood of falling and hence the risk of fall-related fractures. In our Rehabilitation Center we adopt the protocol shown in Table 3 to treat osteoporosis/osteopenia and to prevent falls [36]. 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.

Sites of application	Trapezius muscle (upper fibers)	Gluteus maximus muscle
	triceps brachii muscle	rectus femoris muscle
	latissimus dorsi muscle	biceps femoris muscle
	quadratus lumborum muscle	tibialis anterior muscle
	rectus abdominis 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	

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

We work with Vibration Sound System® (Vissman s.r.l., Roma, Italy): it consists of a 32,000-revolution turbine with a flow rate of 35 m³/hour able to generate air waves with a pressure up to 250 mbar, and of a flow modulator which makes air vibrate with a pressure up to 630 mbar and a frequency up to 980 Hz (however, frequency within 300 Hz is recommended) producing mechano-acoustic waves. For example, we work with ViSS® to carry out eccentric exercises in upright position on Bosu ball, a half-sphere-shaped unstable platform, composed of a hard and a rubber hemispherical platform.

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 Vibration Sound System® with a proprioceptive system called Synergy Mat®.

Conclusions

In conclusion, the use of vibration has an important place in the history of rehabilitation with physical means. Clinical evidences and our experiences have shown satisfactory outcome; nonetheless many potential applications need to be explored, especially referring to potential reparative-regenerative effects. Recent experimental evidence in both animal models and humans, demonstrate that mechanical vibrations increase the regenerative potential of muscular tissue. The regenerative potential is substantially associated with the presence of "satellite cells" by transmitting the internal forces to the extracellular collagen network. That is why observations on the mechano-transduction, that generates mechanical energy through a biochemical signal producing a bio-stimulating effect, is encouraging in this field.

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