REVIEW ARTICLE

Vibration in Neurorehabilitation: a narrative review

Raoul Saggini[1], Rosa Grazia Bellomo[2], Lucia Cosenza[3]

Affiliation:

1 *MD, Full Professor of PRM, Department of Medical Sciences, Oral and Biotechnology, "G. d'Annunzio" University, Chieti, Italy*

2 *MD, Full Professor of PRM, Department of Biomolecular Sciences, "Carlo Bo" University, Urbino, Italy*

3 *MD, School of Specialties in PRM, "G. d'Annunzio" University, Chieti, Italy*

* **Corresponding author:** Raoul Saggini, V.le Abruzzo 322, 66100 Chieti, Italy, E-mail: raoul.saggini@unich.it

Abstract

Over the last decade, vibrations applied to the physical and rehabilitation medicine have been extensively investigated, including the neurorehabilitation, a field where giant steps have been taken in understanding both pathophysiology of the diseases and the influence of vibrational energy on the nervous system.

The purpose of this review is to understand the point at which knowledge is on this topic, what kind of vibration and what modes of applications are used in the rehabilitation of subjects suffering from pathologies affecting the nervous system.

Studies of the last 36 months available on Ovid MEDLINE, PEDro, PubMed Central have been consulted.

The review has shown a positive impact, particularly for focused vibration, in the treatment of neurological disorders.

Keywords: Neurorehabilitation, vibration, multiple sclerosis, Parkinson, spinal cord injury, stroke

1. Introduction

The increasing incidence of neurological disorders and the severity of the disability that they result in, are urgently seeking solutions to prevent or stop the progression of damage and to optimize residual capacity.

Valuable help comes from the vibration world.

The use of vibration in rehabilitation dates back to 1880 when French neurologist Jean-Martin Charcot observed in patients suffering from Parkinson's disease, a reduction in tremor and a better rest after a train trip or a horseback riding. From here, the creation of a chair that reproduced the same carriage movement, the first example of whole body vibration (WBV).[1]

Since then, many studies have been carried out to understand the mechanism of action and to try to standardize protocols in order to achieve specific results. It has come to understand that WBV has limited effects, as it is necessary to work at low frequencies

(15-60 Hz) to avoid adverse effects.

These limits are overcome with focused vibrations, which allow to apply frequencies above 300 Hz directly on the area to be treated.[2]

2. Vibration

For vibration is meant an oscillation around an equilibrium point. Considering that matter is made of particles that move by a force and then tend to return to their point of balance, we can say that everything vibrates.[3] Every day the human body is subjected to vibrations, which can have positive or negative effects depending on the type, duration, surface with the vibrating object. Vibrating perception is in fact a mechanical sensitivity and, therefore, involves specialized receptor structures, present in different tissues, such as mechanical receptors.

Among these, the hair follicles receptors and Meissner corpuscles respond to repetitive stimuli of 30-40 Hz, while Pacini corpuscles preferentially respond to 250 Hz stimuli.

Meissner corpuscles are found in papillary dermis crests and have maximum sensitivity and minimum threshold value. Pacini corpuscles are deeper in the skin and are the ones most involved in vibratory perception: to confirm this hypothesis, elevation of the vibratory perception threshold concomitantly with a loss of Pacini corpuscles in the elderly individual.[4]

These receptors are reached by myelinated fibers of the Aß type and the size of the receptive field increases with the depth of the position, so the Pacini corpuscles have the largest receptive field.

The application of mechanical vibration on the muscle and / or on the tendon structure activates neuromuscular spindle receptors, at the level of the muscle-tendinous complex directly stressed and adjacent muscle groups.[5]

This type of response from muscle to vibratory stress is referred to as "vibration tonic reflection" (RTV). It is scientifically widely documented that RTV induces an increase in contractile strength of the muscle groups involved. These changes in the neuromuscular response are attributable mainly to the increase in the activity of the upper motor centers [6] and the substantial improvement in the nerve commands regulating the neuromuscular response.

In fact, the musculotendinous complex subjected to vibration is endowed with modest, but significant, rhythmic changes in its length [7], which make the vibration training VT substantially equivalent to a successive cadence of concentric and eccentric contractions of small amplitude.

3. Multiple sclerosis

Multiple sclerosis is a chronic inflammatory disease of the central nervous system, often diagnosed at a young age, characterized by abnormal gait, fatigue and increased risk of falls, but also spasticity and bladder dysfunction. An intervention aimed at the recovery of physical and psycho-social skills, it is important to reduce disability and other symptoms related to MS such as fatigue, balance, trunk control. The reduction of fatigue also results in an improved quality of life in terms of pain reduction, depression, anxiety.

The incidence of this disease and the impact that this has on the quality of life of these patients, has stimulated research to find therapeutic intervention especially effective in stopping the progression of symptoms and reduce disability. In this sense, many works, unfortunately with discordant results especially regarding WBV, have been produced on vibration in recent years.

A meta-analysis based on 7 randomized controlled trials, with a total of 250 MS patients involved, of which 109 were part of experimental groups and 100 of control

groups, concluded that WBV may be a benefit only in patients with low degree of disability and only on resistance, while in subjects with severe impairment of motor function and balance the results are scarce and lacking significance even only for endurance.[8]

Uszynski et al. conducted a study in 2015, by randomizing 27 patients into two groups, one of which is subjected only to physical exercise and one to WBV (vibrating platform with the frequency set to 40 Hz) and physical exercise. The difference between this study and others is also in outcome measures: an isokinetic dynamometer was used to measure the variation of muscle strength, and a more comprehensive test for the balance (Mini-BESTEST), and Neurothesiometer to assess the threshold of Perception of vibration. The main limitation of this study is the sample size (only 27 patients) making the results unreliable, even if an average increase of 31.2 meters in 6 minutes walking test in the WBV group compared to only 5 meters in the control group, is impressive.[9]

Clearly positive results returns the study of Yang et al. according to an 8-week WBV program at a frequency of 20 Hz, 5 repetitions of 1 ('per session interrupted by 1' rest) and knees bent at 20 °, it can improve pz conditions with SM. In particular, it increases the flexibility of the ankle joint that contrasts foot drop in these patients, reduces the fear of falling and there is also an increase in ultrasonic bone density measured as t-score.[10]

Uniformity of opinion is regarding the focused vibration.

The study of Camerota et al. conducted on 14 patients with secondary progressive SM, affected by spasticity in the lower limbs unresponsive to drugs, showed significant improvement in the gait and an increase in hip, knee and ankle ROM associated with the stimulus that vibration, applied to the quadricipite muscle and lumbar paraspins, convey to the SNC, restoring motor-sensor integration.[11]

Even in the absence of spasticity, it has been seen that focused vibration has positive effects on postural control and balance: Spina et al involved 20 patients with MS, dividing them into an experimental group and a sham. The device used was applied for one hour per day for 5 days a week x 3 weeks with interruption on the 4th and 7th days. The point of application varies depending on the prevalent disorder. Only the experimental group has reported improvements in the dynamic evaluation of the path. Another encouraging factor is the significance of fatigue severity scale (FSS), patient-related improvement resulting from efficacy of therapy [12] and by interference between proprioceptive circuits, stimulated by vibration, and central circuits of fatigue. [13]

The doubts about this study concern the lack of a standardized protocol and well-defined, as well as the small number of patients.

4. Parkinson

Parkinson's disease results from the degeneration of the dopaminergic cells of the compacts pars of Sömmering substantia nigra but also of other nuclei of the trunk of the brain and of the temporal, limbic and frontal cortex. The biochemical consequence is the functional denervation of the striatum, the main synaptic projection of neurons of the pars compacta of the substantia nigra. The disorders develop when the levels of dopamine in the striatum are reduced to 50-70% of normal, and the pharmacological re-establishment of dopaminergic transmission is the basis for the symptomatic treatment of the disease.

The cardinal signs of Parkinson's disease include resting tremor, rigidity, bradykinesia, and postural instability.

Vibration can be useful in treating these clinical manifestations.

In particular, it is seen that the vibration applied on key ditretti, such as paraspinal lumbar, quadriceps and erector spinae, influence the length of the step and the walking speed. [14, 15]

Benefits not to be neglected are neuromuscular activation and metabolic mechanisms that are activated by WBV acting on bone and skeletal muscle, giving greater strength and resilience, and the proprioceptive stimulus following pathways that do not intercept the base ganglia, thus improving Postural stability and walking followed by neuronal circuits not affected by the disease.[16]

In addition, a rehabilitation program based on vibratory stimulation, is a valuable tool for corticalizzare the gait cycle, which is compromised in Parkinson's.

Based on this background knowledge, studies in recent literature do not show any significant effects of whole body vibration (WBV) comparisons with placebo or other active treatments, with results regarding highly variable balance and mobility.

In fact, the effects of WBV diminish as the distance from the contact area increases, failing to reach high values except with the potential for harmful effects in particular of the joints and spine.[17]

Kaut et al. in a study of 2015 [18] reported positive effects induced by WBV, in particular, it shows significant improvement in-the postural stability for the group subjected to the experimental protocol. Even the comparative analysis of the results reported in the 2 groups, experimental and sham, is significant with respect to this data. Other parameters (tremor, stiffness, bradycin) evaluated at zero time and after therapy are improved, but not significantly. In this study it is specified that the positive effects of WBV derive from the type of generation of vibration, which is stochastic (nonsinusoidal, random) vibratory (SRT). The next step will be to evaluate, with fMRI, whether in Parkinson's patients are activated and enhanced by SRT, vicarious circuits that have been found to be more active in these patients according to cerebral blood flow studies with PET,[19] whereas, Kaut, in a preliminary study with fMRI, has noticed an activation of circuits involved in the control of posture and gait in young healthy subjects undergoing SRT.[20]

Studies are in progress on the effectiveness of a new device that, thanks to heat emitted by the skin, converts the thermal energy into mechanical vibrational energy, self-producing a continuous micromotion. Since the posture is influenced by proprioceptive information and that vibration can convey this type of stimulus, Fox et al., have set up a study randomizing patients with Parkinson's disease in two groups, an experimental and a sham ones. They applied specific devices on the 7th cervical vertebra and on both tendons of the soleus muscle, in agreement with previous studies on the variations of the center of pressure-induced vibration of paraspinal muscles.[21] Patients in the experimental group showed significant and lasting results with regard to the rate of falls both at T1 (end of treatment) and T2 (2 months after the end of treatment), as well as a significant reduction in the oscillation area, which is correlated with the reduction of the rate of falls.[22]

It is thus confirmed the effectiveness of the vibration, in particular focused, but also the stochastic type WBV and integrated with other therapeutic interventions, can play an important role in improving the quality of life of patients diagnosed with PD, especially reducing the risk of falls.

5. Spinal Cord Injury

For this type of neurological deficit, there are many studies that seek to evaluate the

effect that can have vibration therapy or its combination with electrical stimulation on different aspects subsequent to the Spinal Cord Injury (SCI). Among the studies of the last 36 months on murine models we see that Minematsu et al. examining the effects of WBV on bone mass and bone trabecular microarchitecture, showing that bone loss occurs rapidly enough after SCI and that, by intervening early (8 days After surgery) with WBV at a frequency of 25 Hz, this effect, mainly due to bone resorption, can be attenuated.[23]

This benefit was also confirmed in another study in which rats were subjected to 2 daily sessions of 15 ' at a frequency of 40 Hz of WBV, five times a week for 35 days: biochemical levels of osteocalcin, changes in gene expression, show a reduction in osteoclastogenesis and a contemporary increase in osteoblastic activity that contrast bone mass loss.[24]

As regards, instead, the hypotrophy that follows to SCI in murine model, the results of the WBV did not reach significance neither when applied individually, nor even if compared with electrostimulation.[24, 25]

In contrast with studies rats, in humans, WBV does not seem to produce any desired anti-osteoporotic effects. Two different studies, one including 9 patients with complete paraplegia, who underwent 20 minutes per day, 5 days a week for 6 months of WBV at a frequency of 34 Hz, [26] and another based on 42 subjects with complete SCI, that were subjected to WBV at a frequency of 30 Hz 3 times a week for 12 months,[27] no statistically significant results were found in both cases on the efficacy of WBV in preventing bone mass reduction.

For the hypotrophy resulting from SCI, recent studies available about WBV are as always discordant: studies by Alizadeh-Meghrazi et al, Bosveld et al, which show WBV positive results on muscular activation assessed with surface EMG,[28, 29] are afterwards questioned in a systematic review by Qiaodan Ji et al., that consider the evidences insufficient and therefore the effectiveness of this therapeutic approach in SCI patients.[30]

In this review was not considered a study by De Silva et al, in which 15 patients with SCI underwent to 5 session of 30 ' at a frequency of 30 Hz with SCI. The results of muscle activation are significant and encourage further research about the application of WBV in the rehabilitation protocols of patients with this nervous damage.[31] An interesting study associates chronic WBV (12 weeks) with electrostimulation and evaluates several parameters that return statistically significant results. In particular, this associated therapy is able to increase blood flow to the limbs, preserve bone density, prevent muscle deterioration.[32] Regarding focused vibration, Gomes-Olman's study conducted on 24 subjects who underwent both median nerve stimulation and focused vibration on the tendon flexion of the fingers, yielded significant results in the hand function and pinch force.[33]

Even Backus et al identified improvements of the hand strength and range of motion with focused vibration (2 or 3 session per week of 20 'to 60 Hz for a total of 25 sessions) on antagonist muscles during robot-assisted movements.[34]

For this kind of neurological deficit, studies continue to be promising but also with poor validity. It should enlist an increasing number of patients and standardize therapeutic protocols and outcome measures in order to have a satisfactory sample for statistical analysis.

6. Stroke

Another important disabling condition of neurological origin is stroke, estimated in 2010 to be the second most common cause of death and the third leading cause of disability-adjusted life-years (DALY). [35]

Current life expectancy in stroke patients is good and this is a reason for maintaining and increasing residual functionality. A further boost was given by the existence of neuroplasticity.[36]

Confirmed by several studies that have paved the way for a new type of rehabilitation: the one based on neuroscience.

Several studies have tested the efficacy of WBV in reducing disability in stroke patients and the effect on different targets, such as balance, muscle activity, spasticity.

For muscle activity Liao et al involved 45 patients with chronic stroke randomising them into 3 groups, including 1 sham, 1 low intensity WBV (20Hz) and one medium-high intensity WBV (30Hz) while performing different exercises, monitoring with surface EMG activity of vastus lateralis and gastrocnemius both of the paretic and non-paretic limbs. The results showed a significant increase in both paretic and nonparetic activity, at low intensity WBV and medium-high intensity WBV.[37]

Instead, the study of Silva et al. does not report equally satisfactory results relating to muscle attivizione documented with surface EMG with a protocol that provides WBV at a high intensity frequency of 50 Hz in 33 subjects with post-stroke hemiparesis. Probably these results are due to the fatigue that is not evaluated in the study. [38]

An interesting review put together 8 trials for a total of 271 participants and evaluated the effects of WBV on balance, gait performance, and mobility in stroke patients. Although there are several limitations, such as different types of vibratory stimulation, insufficient number of trials, different start of stroke therapy, the authors conclude that there is insufficient evidence to support WBV efficacy in stroke.[39]

Alternative to WBV is focused vibration, which in the field of neurorehabilitation is widely used with satisfactory results.

In contrast to the results of the WBV, focused vibration can induce muscle activation as seen by Paoloni et al. in a study conducted on 22 patients with chronic stroke, randomized into 2 groups, experimental and control ones.

Both groups undergo conventional physiotherapy 5 times a week for 2 weeks; the experimental group also received a session of 30' of focused vibration at 120 Hz on brachial biceps and flexor carpi ulnaris. Muscle activity, registered with surface EMG, revealed an improvement in pre-activation in the group undergoing focused vibration and also a reduction in co-contraction index values (CCI), [40] this probably reflects the data present in literature about plastic remodeling of SNC stimulated by vibration, that improves finalized movement.[41]

A significant effect in neurorehabilitation of stroke is the reduction of spasticity that can be favored by the focused vibration as evidenced by Etoh et al in a study involving 33 patients in repetitive exercise facilitation, assisting therapeutic intervention with electrical stimulation (NMES) or vibratory (DAVS) or transcranial magnetic stimulation (rTMS) or with a combination of all 3 types of stimulation (rTMS + DAVS + NMES). The best results from a clinical point of view of the function were obtained with NMES and DAVS after 4 weeks of therapy. Specifically, DAVS conducted at 91 Hz on elbow and wrist flexors, improves the function of the impaired upper limb in stroke patients, reducing spasticity.[42]

The efficacy of focused vibration in patients with stroke diagnosis was further confirmed by a study in which 18 patients were randomized into 3 groups, of which 1 were subject only to conventional physiotherapy, 1 to conventional physiotherapy and focused vibration, 1 to focused vibration and progressive modular rebalancing (RMP). Focused vibration was applied with a

transducer placed perpendicular to the tendon insertion of the pectoralis minor and brachial biceps muscles simultaneously treated, and flexor carpis treated in a second session on the same day. For each district, were delivered 3 separate sessions of 10' separated by 1' of rest, at a frequency of 100 Hz, for 3 consecutive days. The best results in terms of Wolf Motor Function Test (WMFT) and motricity index (MI) are better in focused vibration groups, especially when it is associated with RMP probably also for the clear pain reduction evaluated with visual analog scales (VAS).[43]

Therapy recently introduced in the treatment of spasticity that may arise from stroke, is injection of botulinum toxin. A study conducted in Italy on 44 patients randomized in 2 groups, of which one subjected only to botulinum toxin injection according to the guidelines, and one subjected to electrostimulation and focused vibration therapy at a frequency of 120 Hz applied to the spastic muscle (2 sessions per week for 3 months in total). It has been shown that integrated intervention with focused vibration can prolong the effects of single drug therapy, can improve spasticity individually and may also modulate painful sensation.[44]

In another study, 30 patients with upper limb spasticity post-stroke were randomized into 2 groups of whom one sham and one experimental. The last one received 100 Hz focalized vibration on brachial triceps. The results are statistically significant and therefore the focused vibration is a non-pharmacological and non-invasive therapeutic approach that can reduce spasticity.[45]

7. Conclusions

Vibration has over time gained an important role in physical and rehabilitative medicine. With the current possibility to use various vibration modality and frequency and with the new evidence in the literature, it is clear that it is becoming an important tool also in the field of neurorabilitation.

At present however, further studies are needed on larger samples of patients with uniform protocols.

References

1. Charcot JM. On Parkinson's disease. In: Lectures on diseases of the nervous system delivered at the Salpêtrière (transl. Sigerson G), pp. 129–156. New Sydenham Society, London.

2. Saggini R, Carmignano SM, Palermo T, Bellomo RG. Mechanical Vibration in Rehabilitation: State of the Art. J Nov Physiother. 2016; 6:314. doi:10.4172/2165-7025.1000314.

3. Saggini R, Ancona E. The applied mechanical vibration as whole-body and focal vibration. In: The mechanical vibration: therapeutic effects and applications. Pp. 25-88. BenthamScience. 2016. DOI: 10.2174/97816810850811170101

4. Cauna N, Mannan G. The structure of human digital Pacinian corpusclesand its functional significance. J Anat (London). 1958; 92: 1-20.

5. Stillman BC. Vibratory Motor Stimulation.A Preliminary Report. The Australian journal of physiotherapy. XVI. 1970.

6. Milner-Brown HS, Stein RB, Lee RG. Synchronization of human motor units: possible roles of exercise and supraspinal reflexes. Electroencephalogr Clin Neurophysiol. 1975;38(3):245-54.

7. Kerschan-Schindl K, Grampp S, Henk C, Resch H, Preisinger E, FialkaMoser V, Imhof H. Whole-body vibration exercise leads to alterations in muscle blood volume. Clin Physiol. 2001; 3: 377–382.

8. Kantele S, Karinkanta S2, Sievänen H. Effects of long-term whole-body vibration training on mobility in patients with multiple sclerosis: A meta-analysis of randomized controlled trials. J Neurol Sci. 2015;358(1-2):31-7. doi: 10.1016/j.jns.2015.09.357

9. Uszynski MK, Purtill H, Donnelly A, Coote S. Comparing the effects of whole-body vibration to standard exercise in ambulatory people with Multiple Sclerosis: a randomised controlled feasibility study. Clin Rehabil. 2016 Jul;30(7):657-68. doi: 10.1177/0269215515595522.

10. Yang F, Finlayson M, Bethoux F, Su X, Dillon L, Maldonado HM. Effects of controlled whole-body vibration training in improving fall risk factors among individuals with multiple sclerosis: A pilot study. Disabil Rehabil. 2016; 15:1-8. DOI: 10.1080/09638288.2016.1262466.

11. Camerota F, Celletti C, Di Sipio E, De Fino C, Simbolotti C, Germanotta M, Mirabella M, Padua L, Nociti V. Focal muscle vibration, an effective rehabilitative approach in severe gait impairment due to multiple sclerosis. J Neurol Sci. 2017;15; 372:33-39. doi: 10.1016/j.jns.2016.11.025

12. Spina E, Carotenuto A, Aceto MG, Cerillo I, Silvestre F, Arace F, Paone P, Orefice G, Iodice R. The effects of mechanical focal vibration on walking impairment in multiple sclerosis patients: A randomized, double-blinded vs placebo study. Restor Neurol Neurosci. 2016; 21;34(5):869-76. doi: 10.3233/RNN-160665.

13. Alfonsi E, Paone P, Tassorelli C, De Icco R, Moglia A, Alvisi E, Sandrini G. Acute effects of highfrequency microfocal vibratory stimulation on the H reflex of the soleus muscle. A double-blind study in healthy subjects. Functional Neurology. 2016; 30(4), 269-274.

14. De Nunzio AM, Grasso M, Nardone A, Godi M, Schieppati M. Alternate rhythmic vibratory stimulation of trunk muscles affects walking cadence and velocity in Parkinson's disease. Clin Neurophysiol 2010; 121(2): 240-7.

15. Camerota F, Celletti C, Suppa A, Galli M, Cimolin V, Filippi GM, De Pandis MF. Focal Muscle Vibration Improves Gait in Parkinson's Disease: A Pilot Randomized, Controlled Trial. Movement Disorders Clinical Practice. 2016; 3(6), 559-566. DOI:10.1002/mdc3.12323

16. Vaugoyeau M, Azulay JP. Role of sensory information in the control of postural orientation in Parkinson's disease. J Neurol Sci. 2010; 289:66-8. doi: 10.1016/j. jns.2009.08.019

17. Sharififar S, Coronado RA, Romero S, Azari H, Thigpen M. The Effects of Whole Body Vibration on Mobility and Balance in Parkinson Disease: a Systematic Review. Iranian Journal of Medical Sciences. 2014;39(4):318-326.

18. Kaut O, Brenig D, Marek M, Allert N, Wüllner U. Postural Stability in Parkinson's Disease Patients Is Improved after Stochastic Resonance Therapy. Parkinson's Disease, vol. 2016, Article ID 7948721, 7 pages, 2016. doi:10.1155/2016/7948721.

19. Payoux P, Brefel-Courbon C, Ory-Magne F, Regragui W, Thalamas C, Balduyck S, Durif F, Azulay JP, Tison F, Blin O, Esquerre JP, Rascol O. Motor activation in multiple system atrophy and Parkinson disease: a PET study. Neurology. 2010;75(13):1174-80.

20. Schneider C, Kaut O, Fließbach K, Wüllner U. Stochastic whole body vibration induced basal ganglia activation. In: Proceedings of the Congress of the German Society of Neurology. Hamburg. Germany. September 2012.

21. Courtine G, De Nunzio AM, Schmid M, Beretta MV, Schieppati M. Stance- and

locomotion-dependent processing of vibration-induced proprioceptive inflow from multiple muscles in humans. J Neurophysiol. 2007; 97: 772–779.

22. Volpe D, Giantin MG, Fasano A. A Wearable Proprioceptive Stabilizer (Equistasi®) for Rehabilitation of Postural Instability in Parkinson's Disease: A Phase II Randomized Double-Blind, Double-Dummy, Controlled Study. PLoS ONE. 2014;9(11): e112065. doi:10.1371/journal.pone.0112065

23. Minematsu A, Nishii Y, Imagita H, Takeshita D, Sakata S. Whole-body vibration can attenuate the deterioration of bone mass and trabecular bone microstructure in rats with spinal cord injury. Spinal Cord. 2016; 54(8):597-603. doi: 10.1038/sc.2015.220.

24. Bramlett HM, Dietrich WD, Marcillo A, et al. Effects of low intensity vibration on bone and muscle in rats with spinal cord injury. Osteoporosis international: a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA. 2014;25(9):2209-2219. doi:10.1007/s00198-014-2748-8.

25. Butezloff MM, Zamarioli A, Maranho DA, Shimano AC. Effect of Electrical Stimulation and Vibration Therapy on Skeletal Muscle Trophism in Rats with Complete Spinal Cord Injury. Am J Phys Med Rehabil. 2015; 94(11):950-7. doi: 10.1097/PHM.0000000000000278.

26. Wuermser LA, Beck LA, Lamb JL, Atkinson EJ, Amin S. The effect of low-magnitude whole body vibration on bone density and microstructure in men and women with chronic motor complete paraplegia. The Journal of Spinal Cord Medicine. 2015;38(2):178-186. doi:10.1179/2045772313Y.0000000191

27. Dudley-Javoroski S, Petrie MA, McHenry CL, Amelon RE, Saha PK, Shields RK. Bone architecture adaptations after spinal cord injury: impact of long-term vibration of a constrained lower limb. Osteoporos Int. 2016; 27(3):1149-1160. doi: 10.1007/s00198-015-3326-4

28. Alizadeh-Meghrazi M, Masani K, Zariffa J, Sayenko DG, Popovic MR and Craven BC. Effect of whole-body vibration on lower-limb EMG activity in subjects with and without spinal cord injury. J Spinal Cord Med 2014; 37(5): 525–536.

29. Bosveld R, Field-Fote EC. Single-dose effects of whole body vibration on quadriceps strength in individuals with motor-incomplete spinal cord injury. J Spinal Cord Med 2015; 38(6): 784–791.

30. Ji Q, He H, Zhang C, Lu C, Zheng Y, Luo XT, He C. Effects of whole-body vibration on neuromuscular performance in individuals with spinal cord injury: A systematic review. Clin Rehabil. 2016; 29.

31. Da Silva U, Villagra HA, Oliva LL, Marconi NF. EMG activity of upper limb on spinal cord injury individuals during whole-body vibration. Physiol Int. 2016;103(3):361-367. doi: 10.1556/2060.103.2016.3.10

32. Menéndez H, Ferrero C, Martín-Hernández J, Figueroa A, Marín PJ, Herrero AJ. Chronic effects of simultaneous electromyostimulation and vibration on leg blood flow in spinal cord injury. Spinal Cord. 2016;54(12):1169-1175. doi: 10.1038/sc.2016.60

33. Gomes-Osman J, Field-Fote EC. Cortical vs. afferent stimulation as an adjunct to functional task practice training: a randomized, comparative pilot study in people with cervical spinal cord injury. Clin Rehabil. 2015; 29(8):771-82. DOI: 10.1177/0269215514556087

34. Backus D, Cordo P, Gillott A, Kandilakis C, Mori M, Raslan AM. Assisted movement with proprioceptive stimulation

reduces impairment and restores function in incomplete spinal cord injury. Arch. Phys. Med. Rehabil. 2014; 95, 1447–1453.

35. Feigin VL, Forouzanfar MH, Krishnamurthi R, Mensah GA, Connor M, Bennett DA, Moran AE, Sacco RL, Anderson L, Truelsen T, O'Donnell M, Venketasubramanian N, Barker-Collo S, Lawes CM, Wang W, Shinohara Y, Witt E, Ezzati M, Naghavi M, Murray C. Global and regional burden of stroke during 1990–2010: findings from the Global Burden of Disease Study 2010. Lancet. 2014;383(9913):245-254.

36. Morris RG. D.O. Hebb: The Organization of Behavior, Wiley: New York; 1949. Brain Res Bull. 1999; 50(5-6):437.

37. Liao LR, Lam FM, Pang MY, Jones AY, Ng GY. Leg muscle activity during whole-body vibration in individuals with chronic stroke. Med Sci Sports Exerc. 2014;46(3):537-45. doi: 10.1249/MSS.0b013e3182a6a006.

38. Silva AT, Dias MP, Calixto R Jr, Carone AL, Martinez BB, Silva AM, Honorato DC. Acute effects of whole-body vibration on the motor function of patients with stroke. American Journal of Physical Medicine & Rehabilitation 2014;93(4):310-319.

39. Yang X, Wang P, Liu C, He C, Reinhardt JD. The effect of whole body vibration on balance, gait performance and mobility in people with stroke: a systematic review and meta-analysis. Clin Rehabil. 2015;29(7):627-38. doi: 10.1177/0269215514552829

40. Paoloni M, Tavernese E, Fini M, Sale P, Franceschini M, Santilli V, Mangone M. Segmental muscle vibration modifies muscle activation during reaching in chronic stroke: A pilot study. NeuroRehabilitation. 2014; 405–414. DOI:10.3233/NRE-141131

41. Tavernese E, Paoloni M, Mangone M, Mandic V, Sale P, Franceschini M, Santilli, V. Segmental muscle vibration improves reaching movement in patients with chronic stroke. A randomized controlled trial. NeuroRehabilitation. 2013; 32(3), 591-599. doi: 10.3233/NRE-130881

42. Etoh S, Noma T, Takiyoshi Y, Arima M, Ohama R, Yokoyama K, Hokazono A, Amano Y, Shimodozono M, Kawahira K. Effects of repetitive facilitative exercise with neuromuscular electrical stimulation, vibratory stimulation and repetitive transcranial magnetic stimulation of the hemiplegic hand in chronic stroke patients. Int J Neurosci. 2016;126(11):1007-12. DOI: 10.3109/00207454.2015.1094473

43. Celletti C, Sinibaldi E, Pierelli F, Monari G, Camerota F Focal Muscle Vibration and Progressive Modular Rebalancing with neurokinetic facilitations in post- stroke recovery of upper limb. Clin Ter. 2017;168(1): e33-e36. doi: 10.7417/CT.2017.1979

44. Saggini R, Scarcello L, Di Stefano A, Carmignano SM, Barassi G, Visciano C, Antonacci R, Scorrano V, Bellomo RG. Integrated rehabilitation treatment of focal spasticity after botulinum toxin type-A injection. Journal of Clinical Trials. 2015, 5:6.

45. Casale R, Damiani C, Maestri R, Fundarò C, Chimento P, Foti C. Localized 100 Hz vibration improves function and reduces upper limb spasticity: a double-blind controlled study. Eur J Phys Rehabil Med. 2014;50(5):495-504.

