Local Application of Vibration in Motor Rehabilitation – Scientific and Practical Considerations

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ABSTRACT

Vibration stimulates specific receptors, cutaneous and musculo-tendinous. The afferent impulses travel through spinal neurons to thalamus and cortical structures. The local muscular response to a vibration is a tonic vibratory reflex. This reflex depends on many factors: frequency, amplitude, and tendon and muscle length. Based upon this reflex, vibration produced alteration of isometric and isotonic contraction, flexibility, spasticity. Many studies investigated facilitator effects on movement in stroke patients and spinal cord injuries. There is further need to set the place of vibration in the therapeutic field of motor control enhancement.

Keywords: Vibration, muscle, facilitation, spasticity.

BACKGROUND

Physiology

Applying a vibratory stimulus on human body is followed by specific receptors activation. These receptors are some cutaneous and muscular receptors.

Cutaneous mechanoceptors are Merkel disks and Meissner corpuscles from the superficial layers and pacinian corpuscles from the deep layers of the skin, fasciae between the muscles and periost. Merkel disks respond to low vibratory frequencies (5 – 15 Hz), Meissner corpuscles to medium frequencies (20-50 Hz) and pacinian corpuscles to high frequencies (60-400 Hz). Judging by adaptability, the Meissner and pacinian corpuscles adapt rapidly, Merkel disks adapt slowly (1). The above-mentioned receptors connect with myelinated afferents, high diameter (type A\(\alpha\), 12-20 \(\mu\)m, speed 72-120 m/s) and medium diameter (A\(\beta\), 6 – 12 \(\mu\)m, speed 36 – 72 m/s). These afferent fibers join the peripheral nerves, then the dorsal root of spinal nerves. They bifurcate, one bundle joining the second-grade neuron from profound strata of posterior horn and another bundle (collateral) joining the dorsal column. The axons of the second-grade neuron join the third-grade neuron in the ipsilateral lateral cervical nucleus. The axons of the third grade neuron cross the median line and join the medial lemniscus from medulla. This is the main road...
for vibratory information. The collateral fibers from first grade neuron travelling in the ipsilateral dorsal column synapse in the dorsal column nuclei of the medulla, where there is somatotropic organization. Fibers from caudal segments are medially situated and join the gracilis nuclei, fibers from proximal segments are laterally situated and synapse in the cuneate nuclei. From gracilis and cuneate nuclei the fibers form the medial lemniscus, which cross the median line and receive collaterals from lateral cervical nucleus. Medial lemniscus ends in ventral postero-lateral nucleus of thalamus.

The face sends vibratory afferents to the neurons in the main nucleus of trigeminal, whose axons enter the trigeminal lemniscus and ends in ventral postero-medial nucleus of thalamus.

The two thalamic nuclei, cortical projections end in the primary somatosensitive S1 area in the postcentral gyrus, on vibration responsive neurons. Both the two thalamic nuclei and S1 area have somatotopic maps of the body. Information from vibratory sensibility and position sense share central pathways but the receptors, thalamic and cortical projection are specific (2).

Muscle vibratory stimulation

Vibration of a musculo-tendinous junction elicits muscular contraction, a phenomenon called tonic vibrator reflex (3). Eklund si Hagbarth used 100 Hz and low amplitude (3 mm) vibration on a relaxed muscle and obtained a contraction after 5 – 45 seconds of stimulation, whose amplitude increases slowly (10 – 60 seconds) until it reaches a plateau (isotonic contraction) and it maintains constant for 20 minutes when the vibration still goes on. This contraction is strong enough to move the body segment and work against a resistance. Ceasing the vibration means in a few seconds ceasing the contraction. Any skeletal muscle responds with a tonic vibratory reflex, except the facial and tongue muscles, which miss neuromuscular spindles. Using vibration on a contracting muscle elicited supplementary force. In the main time, the principal antagonist of the vibrated muscle relaxed (4).

The pathway of this reflex streams with the afferents from neuromuscular spindle (primary terminations, Ia) from nuclear bags and nuclear chain fibers, which intermediate also tonic and phasic stretch reflex. Secondary terminations and Golgi organs are less sensitive to vibration. Primary terminations end in spinal motoneurons to elicit a tonic contraction of the vibrated muscle. Above the spinal mechanism, there is supraspinal control, as seen by reflex disappearance in spinal sections above C1 and its persistence in laboratory animals with postcollicular decerebration. Lateral vestibular nucleus ablation diminishes the reflex by 20 – 40%.

Tonic vibratory reflex depends on more factors.

Vibration frequency is the main factor. Homma identified variable effects of different frequencies. Low frequencies, 20 – 50 Hz, produce muscular relaxation. Although some studies suggest that lateral gastrocnemius and some other few muscles contract as a response to 40 – 60 Hz frequencies. Other researchers consider that the 50 Hz frequency is more facilitatory than lower one (30 Hz) (5). Stimulation rates between 80 – 120 Hz elicit the classic tonic vibratory reflex, and frequencies between 100 – 200 Hz determine postvibratory facilitation (6). Frequencies above 200 Hz can damage the skin; even those around 150 Hz may induce pain and discomfort.

The most widely used stimulation rates are in the interval 100 – 150 Hz, they augment electromiographic activity of the muscle and the synchronization if motor units (7).

Vibration amplitude is defined by the amount of displacement of muscle fibers. High amplitudes produce adverse reactions, especially in patients with cerebellar lesions. Optimal values are between 1 and 2 mm.

As a consequence, a therapeutical vibration is defined by a rather high frequency (100-150 Hz), low amplitude (1-2 mm) and has to be applied on musculo-tendinous junction.

There are interpersonal factors (response variability in individuals) and intrapersonal factors (response variability in the same person at different moments) to influence tonic vibrator reflex.

Vibrated muscle length modifies the tonic vibrator reflex: vibrating a stretched muscle elicits a stronger reflex, through enhanced neuromuscular spindle sensibility with length.
Tendon physical proprieties determine different intensities of TVR in different muscles, with quadriceps and sural triceps being the latest to respond.

Some other factors which alter TVR are the head and body positions. Head rotation implies a stronger reflex on the extremities on which the eyes are set and diminished on contralateral side. This is due to extensor facilitation through neck asymmetric tonic reflex. Supine position is preferred for extensor stimulation and prone position for flexor stimulation.

Vibratory effect can be altered when associating some other modalities. Cutaneous pressure has inhibitory action and, when combined with vibration facilitator response, may annihilate the later.

Precautions

Vibrating an immobilized segment may enhance the risk of thrombosis. Vibration applied close to a vessel may displace a thrombus and produce embolus. Care must be taken when vibrating the skin with altered elastic properties as the friction may injure it.

Rehabilitation programs and TVR

As a diagnostic tool, TVR has a limited importance. Some studies focused on efficacy of miorelaxants drugs, considering the removal of TVR as a measure of drug efficiency. Other interest was in the ataxic cerebellar diseases, to evaluate the sensibility of gamma efferent system. Some scholars recommend the TVR instead of osteotendinous reflex to evaluate the stretch reflex components.

Therapeutic use of TVR is far more important, as local and general application. In the present paper we focus on local use.

Local application implies agonist facilitation, hypertonia reduction, flexibility enhancement. Whole body application facilitates postural tone and balance and is made through both feet in orthostatism.

Isometric contraction

Isometric contraction concomitant with vibratory stimulus produced a significant high amount of muscular force (8).

Isotonic contraction

A weak contraction was facilitates by vibration, with the result of an increase 10-20 folds of voluntary maximal contraction; the mechanism was enhancement of afferent information from neuromuscular spindle.

Prehension force, as a dynamic contraction of low and medium-intensity was enhanced by 52% when vibrating with 40 Hz (9). Better results on strength are seen when vibrating the stretched muscle. The mechanism responsible is the alteration of cortical excitability in main motor area M1, opposed to vibrated muscle. Concomitantly, there are complementary alterations in agonist-antagonist coupling. All these alterations were noted for a prolonged duration of time (10).

Enhancing flexibility

Studies were done on adductor flexibility. The vibratory stimulus acted through enhancing pain threshold, enhancing local blood supply, muscle relaxation (11).

Remanence of the vibratory effects was documented by transcortical magnetic stimulation. The vibration of a contracting muscle produces long-term alteration of cortical excitability in contralateral main motor area, lasting up to 2 weeks in normal people. The alterations were muscle-specific. After 3 weeks the excitability came to pre-stimulation status.

Some controversial results arise using different stimulation duration. Short stimulation (seconds or cyclic stimulation 2 s on, 2 s off) resulted in antagonist suppression. Prolonged application, 60 minutes, resulted in cortical inhibition of agonist and activation of antagonist, suggesting overpassing spinal reciprocal inhibition and promoting cortical mechanisms, mostly using GABA (10).

Reducing muscle hypertonia is important in upper neuron lesions and acts through reciprocal inhibition laws.

Spastic muscles were studied first in 1968 and produced inconstant results. Hagbarth and Eklund publish a study on 150 Hz vibration on some tendons (hand flexors, ankle) in patients with upper neuron lesions. They focused on resting muscle, contracting muscle and resistance on passive stretching. They noted differences in duration and intensity of TVR between normal and spastic resting muscle. During contraction, vibration of spastic muscle produced inconstant results and vibration of its antagonist increased segmental range of motion (12).

Magnetic transcranial stimulation of motor cortex elicits evoked motor potentials in the...
These motor evoked potentials are modulated by peripheral afferents, such as electrical or vibrated stimuli. The interaction point of afferents is still in debate. It is already known that in normal individuals, cutaneous application of low (30 Hz) and high (130 Hz) vibrations reduces the duration of motor evoked potentials.

Cutaneous application of low frequency (30 Hz) on spastic side had a similar effect, but this was not seen with 130 Hz. The facilitator effect of 130 Hz was seen on both sides, including the non-affected one. There is a suggestion that different frequencies act on peculiar levels of CNS. High frequency afferents could facilitate spinal neurons, and the fact that low frequencies have similar facilitator effect suggests that, at least in the first stages, there is no transcortical inhibition. This study opens the gate for research on influences of afferents on cortical reorganization (13).

Tendon vibration was used on patients with chronic stroke and longstanding spasticity (14). 100 Hz vibration of triceps brachialis lowered the biceps brachialis spasticity (agonist) and the association with physical therapies led to a better effect (higher and faster) both on spasticity reduction and on motor control augmentation. These results were noted for a minimum 48 h. The researchers concluded that vibration activates both central mechanisms (inhibition of cortico-spinal activity) and spinal mechanisms (reciprocal inhibition). In fact, the spinal level is the first to interact with vibratory stimulus, improving agonist antagonist coupling. For the cortical level, vibratory afferent increase the cortical silence period. These functional alteration are maintained long after the stimulus ceased, proving persistent neuronal alteration (15, 16).

Another application technique used the vibration on lengthened spastic agonist, which elicited a strong contraction followed by relaxation and spasticity removal for 30 minutes. Simple prolonged stretch (in orthosis for instance) of a spastic muscle reduced the spasticity during the maneuver and little afterwards, for about 5 minutes. Antispastic mechanism of vibration may include the alteration of motor cortex excitability (17).

Electrophysiology studies mentioned the so-called paradox of vibration. In the same time with vibratory tonic reflex, on the same muscles, there was a reduction of Hofmann reflex, suggesting that vibration modulates the excitability of stretch reflex, which plays a role in spasticity.

Gurfinkel proved that, on normal individuals, vibration of different muscular groups of lower limb result in stepping, through spinal activator mechanism of central pattern generators (CPG) (18). CPG is an organization pattern of neuronal circuits which is responsible with well-coordinated and high reproducible movements, which reside in lumbosacral segments in human. In the case of medullar lesion, the interruption of communication between the superior levels and spine is followed by deficit of spinal CPG activation. In case of complete SCI, epidural electrical stimulation of lumbosacral region produced cyclic movements of stepping and in incomplete SCI, the same stimulation improved the gait.

Similar result were reported in normal individuals and in complete and incomplete SCI using vibration on quadriceps, hamstrings and tensor fascia lata (19).

The best walking patterns were obtained with vibration on pelvis stabilizations (tensor fascia lata) compared with vibration on muscles which are strongly active during gait (quadriceps, hamstrings), probably due to the fact that coxofemoral muscles have important influence on spinal CPG. The effects were persistent, at least for one month after treatment, suggesting the hypothesis of spinal remodeling (20, 21).

Patients with incomplete SCI have a higher number and prolonged clonus cycles compared with complete SCI. In incomplete SCI, prolonged vibration of lower limb muscles reduced spasticity (on Modified Ashworth Scale), clonus and increased range of motion (22).

There are a limited number of studies on children with cerebral palsy. A paper on a study on 89 children compared the vibration and physical therapy versus physical therapy alone for 12 weeks, twice a week. The outcome was spasticity and gross motor function. The results were significantly better for the vibration and physical therapy group, with maintenance of 3 months. These result are the starting point for introduction of vibration in the therapeutically armamentarium of children with cerebral palsy (23).

As far as we know by now, the local vibration is a potential facilitator therapy for movement in motor disorders, in adults and in children. There is interest in papers and studies to
establish the exact amount of stimulation, the frequencies and the associations with physical therapies.

CONCLUSION

A vibratory stimulus, applied locally on the musculo-tendinous junction, with a high frequency and a low amplitudes, is to be included in the rehabilitation protocols for specific objectives, as contractility and flexibility modulation. The reduction of hypertonia in central motor lesions must be further evaluated, in order to facilitate the physical exercise for these patients.

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