Production, Delivery and Application of Vibration Energy in Healthcare

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In Rehabilitation Medicine therapeutic application of vibration energy in specific clinical treatments and in sport rehabilitation is being affirmed more and more. Vibration exposure can have positive or negative effects on the human body depending on the features and time of the characterizing wave. The human body is constantly subjected to different kinds of vibrations, inducing bones and muscles to actively modify their structure and metabolism in order to fulfill the required functions. Like every other machine, the body supports only certain vibration energy levels over which long term impairments can be recognized. As shown in literature anyway, short periods of vibration exposure and specific frequency values can determine positive adjustments.

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I. VIBRATIONS AND THEIR PECULIAR PARAMETERS

In Rehabilitation Medicine therapeutic application of vibration energy in specific clinical treatments and in sport rehabilitation is being affirmed more and more. Vibrations are characterized by small amplitude waves which usually overlap the cinematic motion of the body: therefore a body vibrates when an oscillating wave motion around a point of reference is drawn. If we look at a vibrating body, we can note periodical movements: the time between two passages of a point through the reference point is called “Period (or cycle)” and the number of cycles accomplished by the vibrating body in a second is defined “Frequency”; the unit of measurement of the frequency is the Hertz that is cycle per second.

Besides frequency, vibrations are characterized by other 3 tightly connected parameters: amplitude movement (expressed in meters according to the International System); velocity (expressed in m/s); acceleration (expressed in m/s² or in acceleration of gravity multiple/submultiple). Acceleration is the measurement of how much quickly the velocity changes in time and it is the most important parameter for the assessment of body response to vibrations: indeed the human body feels more the variation of a stimulus than its persisting. The intensity of vibration is usually represented by the Acceleration Root Mean Square. Formally, the Effective Value of the acceleration is expressed as follows:

\[ a_{eff} = \sqrt{\frac{1}{T} \int_0^T a^2(t) dt} \]

In matter of vibration energy it’s needful to remember that every vibrating body has an its own resonance frequency and the body vibration amplitude changes depending on this specific frequency: specially, when the body vibrates at its resonance frequency, the vibration is ampli-
fied and the maximum vibration amplitude is theoretically infinite.

| FIG. 2: The resonance frequency. |

II. VIBRATIONS PRODUCING METHODS

It is possible to produce mechanical vibrations by using the centripetal force generated by a body rotating around a non barycentric axis. In this case the system is equivalent to a concentrated mass rotating around the rotation axis with a constant angular velocity \( \Omega \); so it moves in uniform circular motion along a circumference whose radius is the eccentricity \( e \), with a velocity that has a constant amplitude, but is continuously changing in orientation and direction. The centripetal force that makes the body vibrate, has the following amplitude

\[
|F(t)| = m\Omega^2 e
\]

And it can be modulated by varying the angular velocity and the distance between the rotating axis and the barycentre.

It is possible to produce vibrations also by using piezoelectric materials. The piezoelectric effect (discovered for the first time in the 1880 by Jacques and Pierre Curie), is due to the crystals specific property of generating a mechanical stress (contraction or expansion) when they are under the influence of an electric field and specially under the influence of an alternating current.

The wave-vibration frequency of the crystal depends on its thickness and on the frequency of the applied alternating current. Piezoelectric crystals are the topaz, the tourmaline but the most one used in the past is the quartz. Today, polycrystalline ceramics as the barium titanate \((BaTiO_3)\) are used in order to reduce the weight and the burden of the vibrating head. Vibrations produced by this method can reach frequency of several MHz.

| FIG. 3: Centripetal force generated by a body rotating around a non barycentric axis. |

An other way to produce vibrations is to use a magnetic-dynamic transducer, commonly installed on the loudspeakers. These kind of transducers are usually formed by a membrane (usually a cone) in contact with an electric coils inside a magnetic field produced by a permanent magnet. When an alternating current goes through the coils, a magnetic field is developed. This magnetic field varies in dependence of the current direction. Thus, the coil is equivalent to a varying intensity magnet that is attracted or not by the permanent magnetic field and so coils vibrate propagating its vibrations to the membrane; these vibrations are spread in the air in the form of a sound.

| FIG. 4: Piezoelectric effect. |

III. BIOMEDICAL VIBRATION APPLICATION

In this chapter we will analyze some examples of biomedical applications using the shown vibration producing methods. Lithotripters use ultrasound high energy wave to shatter renal cal-
culi, and these vibrations can be produced by using both piezoelectric and magnetic-dynamic effect. Dental scalers use piezoelectric effect to generate high frequency oscillations (20-80 KHz), with very small amplitude and this allows to remove the dental plaque.

All ultrasound probes use piezoelectric effect, the abdominal one, the vascular one, etc.

Ultrasound Rehabilitation devices generate vibration of 1-3 MHz frequency to treat neuritis, epicondylitis and so on. Next, in rehabilitation vibration therapy exercise medical devices generating vibrations by oscillating masses are used.

IV. VIBRATIONS HUMAN BODY EFFECTS

At this point of our paper, after analyzing the peculiar parameters of vibrations and after discussing several vibration production methods, we will examine their effect on human body. Each day, human body is subject to many vibration tipologies which can have positive or negative effects on it. We have previously analyzed that the acceleration is the most important parameter to assess body response to the vibrations, but it’s important to underline that also the time exposure, the contact area, the contact force, the resonance frequency of tissues, the ergonomic and environmental factors are determinant. Mechanical vibrations affecting human body during the daily life are classified in three main frequency bands:

- **0 - 2 Hz** → low frequency oscillations, generated by means of transportation (buses, airplains, ships);
- **2 - 40 Hz** → middle frequency oscillations, generated by machine tools and industrial plant;
- **> 40 - 50 Hz** → high frequency oscillations generated by a lot of vibrating tools used in industrial field.

A. **Negative effects**

The main problem connected to vibrations is the vibration wave energy that is transferred from the oscillation source to the exposed body,
because this energy causes different effects on human tissues and organs crossed, before its dissipation. Human body, as every machine, can tolerate only certain vibration energy levels, beyond which, as consequence, because of long terms damages, it starts to deteriorate. Human body doesn’t vibrate like a single mass with only one natural frequency: organs and separately every body part has a their own resonance frequency: so, vibrations between 1-4 Hz make great resonance on neck vertebrae (with an amplification also of 240%), associated to dyspnea symptomatology; 4-6 Hz vibration frequency cause the resonance of the brain area causing sleepiness and attention loss; mechanical oscillations with a frequency of 20-30 Hz hit the resonance of the vertebral column, with 240% amplification, inducing cervical and low back pain, while a frequency of 40 Hz, that is the resonance frequency of the ocular area, causes a decrease of image focusing ability of the person. Besides the propagation direction of vibration (indeed the oscillations can occur in vertical or horizontal wise, in linear or in rotatory way) the touch point must be known. This is the reason why vibrations are also classified in:

- **WBV** - whole body vibrations: vibrations carried on the whole body;
- **HAV** - hand-arm vibrations: vibrations carried on the hand-arm system;
- **LV** - Local vibrations: vibrations involving only specific body parts.

WBV are low-middle frequency vibrations inducing physiological effects that are able to modify the efficiency degree and to decrease the fatigue threshold. Human body antagonizes the effect of these vibrations increasing the muscle tone and modifying the locomotive apparatus, stimulated in a reflex way by the vestibular system. Otherwise, HAV are high frequency oscillations generated by common industrial tools, characterized by a limited propagation area, the touch area, that produce local negative effects. The smallest parts of our body have high resonance frequencies therefore, high frequency vibrations cause the resonance of every upper art components, inducing the negative effects. Human tissues have a great attenuation ability, therefore the effects of these oscillation frequencies are limited to the contact area. LV are middle-high frequency vibrations producing local effects, but not only on the hand-arm system.

### B. Safety of workers subject to vibrations

Many people are daily exposed to mechanical vibration risks: in order to reduce the negative effects of vibration on workers (vascular, muscle disease and neurological problems caused by HAV or low back pain connected to Whole body vibrations, the Italian Government has approved specific regulations to improve the worker’s safety. These rules are reported in D.Lgs 81/08 [1] that encloses also the rudiments of Dlgs. 187/2005. The legislative text sets the daily exposure limit value of the Hand - Arm system at 5 \( m/s^2 \) while the limit value of the whole body vibrations is stated at 1.15 \( m/s^2 \). This exposure value is quantified by the evaluation of an equivalent acceleration, normalized on a reference period of 8 hours. The equivalent acceleration of Hand - Arm system is calculated as follows:

\[
A^*(8) = A(w)_{sum} \sqrt{ \frac{T_e}{8} } \tag{1}
\]

where:

- \( T_e = \) daily exposure time to vibrations (hours),
- \( 8 = \) reference time (hours)

\[
A(w)_{sum} = \sqrt{(a_x^2 + a_y^2 + a_z^2)}
\]

where \( a_x, a_y, a_z = \) r.m.s. acceleration values (in \( m/s^2 \)) along \( x, y, z \) axis (ISO 5349-1: 2001) while concerning the whole body

\[
A^*(8) = A_{\text{Max}} \sqrt{ \frac{T_e}{8} }
\]

where:

- \( T_e = \) daily exposure time to vibrations (hours),
- \( 8 = \) reference time (hours),
- \( A_{\text{Max}} = \) maximum value among \( a_x, a_y, a_z \),
- \( a_x, a_y, a_z = \) r.m.s acceleration values (in \( m/s^2 \)) along \( x, y, z \).

### C. Positive effects

However, reduced exposure time and oscillations frequency of 15-50 Hz, induce positive human body-adaptations, as shown in a lot of scientific studies. These positive adjustments acting on the skeletal and neuro-muscular system [2] are both metabolic and mechanical.
D. Therapeutic applications of vibration Energy in rehabilitation medicine

In our lecture, not focusing on ultrasound therapy in rehabilitation medicine, we can affirm that in the actual practise, mechanisms of therapeutic vibration applications use the first vibration producing method, i.e. the rotation/oscillation of especially designed masses controlled by ad hoc electrical engines. Depending on desired vibrations typology, these mechanism are classified in: WBV - whole body vibrations propagated to the whole body by using vibrating platform; HAV - hand-arm vibrations delivered to the hand-arm system by using a vibrating tool. After focusing the idea that vibrations at specific frequency, if applied by using appropriate instrumentation, induce positive effects on human body, we go to discuss them specifically.

E. Hormonal effects

Vibration therapeutic exercise is liable for several hormonal concentration variations, as shown in many clinical studies performed on a statistical group of people subject to vibrations with 20-50 Hz oscillations frequency. Particularly, vibrations cause an increase of testosterone and growth-hormone concentration, and contextually a decrease of cortisol concentration. The effect on Testosternone and GH has reference to muscular-metabolic receptors, while the Cortisol decrease is probably due to an insufficient stimulation of feedback nervous in the skeletal muscles.

F. Effects on neuro-muscular system

Several authors show that vibration energy produces a motor nerve activation variation, particularly it induces a strengthening of the stimulation influx, through the spindle motor-neural connections, i.e. the myotatic reflex (stretch reflex). Vibrations applied locally to the muscle and to tendon structure (10-40 Hz) and whole body vibrations (1-50 Hz) cause the muscle spindle receptors activation in the area directly stimulated, but also in contiguous muscular groups. This kind of vibration muscle response is defined Vibration Tonic Reflex. Vibration Therapeutic Exercise implicates a biological adaptation correlated to a neural strengthening effect, similar to the enhancement induced by the force and power training. Authors show that Vibration Therapeutic Exercise
is able to improve the human explosive power ability thanks to a better motor unit synchronization and an improvement of synergistic muscles coordination together with an antagonist muscles inhibition.

FIG. 11: Increase of contractile ability in muscular area subject to vibration exercise induces an evident “right-shift” of force-velocity curve and of force-power one.

G. Bone tissue effects

So, Vibrations Therapeutic Exercise (VTE) induces a clear muscular function improvement that produce also effective stress on insertion bone; the force generated by muscular tissue is strongly connected to the bone mass development and to its mechanical resistance ability. VTE causes an intense skeletal and muscular system mechanical stress, without requiring patient’s dedication: this is the reason why this therapeutic exercise is particularly suitable for some clinical cases. Mechanical vibration action to bone remodelling mechanism is observable and reported in a lot of clinical studies made on patients affected by bone fracture or osteoporosis: in both cases, patients have shown a really increase of the osteogenic activity. Indeed vibration therapy is able to positively interfere on bone metabolism, also in osteoporotic degeneration case and because of the scientific evidences of its effectiveness in Bone Mass Density improvement, it is possible to consider vibration exercise as a therapy of choice concerning the geriatric medicine and the osteoporosis prevention. Having established the VTE effects on patients affected by osteoporosis, all the more so it is applicable with good results to upper and lower limb bone fractures. VTE induces a bone growth acceleration that enable the broken bone reparation in less time than usual. All these clinical effects are basically due to the important role that the mechanical factor has concerning the bone tissue adaptive response: indeed osteocytes have mechanical receptors reacting to the variation of bone deformation, producing a signal proportional to the applied load. This signal is sent to the osteoblast that, consequently, are activated inducing an osteoblastic activity improvement and therefore an increase of bone forming.

V. CONCLUSIONS

In our current discussion, we have widely analyzed the vibration phenomenon: first of all we have studied its peculiar parameters, then we have dealt with some vibration producing methods, finally we have examined human body vibration effects. Now, we are aware that these effects can be really positive for human body, provided that vibration energy is applied on patient by qualified clinicians using appropriate procedures, with frequency whose good results have been scientifically proved. It’s undeniable that, stated these conditions, the mechanical vibrations therapeutic exercise is a strong good stimulus for the whole body, applicable to various fields:

- in rehabilitation plans in which, an optimization of methods aimed at osteoblastic activity and extensibility muscle-tendon complex improvement, is required;
- in geriatric patologies, to improve myo-osseo-articular functionality and in osteoporotic patients;
- in sport field as alternative/complementary training method oriented to an explosive-force improvement;
• in workplans oriented to painful pathologies such as in chronic low back-pain therapy.

In conclusion, we remark again that WBV treatments, if applied in non specific way, could have non positive effects because, as told before, human body is a system with n-degrees of freedom, where every element has their own resonance frequency. The optimum is obtained localizing vibrations to a specific body part, focusing vibration effects, avoiding useless dispersions. This is the reason why vibration application mechanisms are crucial: in treatments where a systemic response is required the appropriate vibration application would be Whole Body Vibrations while in treatment that focus on a specific and local body segment the best solution would be Local Vibrations.

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