Oximetry: a new non-invasive method to detect metabolic effects induced by a local application of mechanical vibration

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Abstract. Mechanical vibrations application is increasingly common in clinical practice due to the effectiveness induced by these stimuli on the human body. Local vibration (LV) application allows to apply and act only where needed, focusing the treatment on the selected body segment. An experimental device for LV application was used to generate the vibrations. The aim of this study was to detect and analyze the metabolic effects induced by LV on the brachial bicep muscle by means of an oximeter. This device monitors tissue and muscle oxygenation using NIRS (Near Infrared Spectroscopy) and is able to determine the concentration of haemoglobin and oxygen saturation in the tissue. In a preliminary stage we also investigated the effects induced by LV application, by measuring blood pressure, heart rate, oxygen saturation and temperature. These data confirmed that the effects induced by LV application are actually localized. The results of the measurements obtained using the oximeter during the vibration application, have shown a variation of the concentrations. In particular an increase of oxygenated haemoglobin was shown, probably caused by an increased muscle activity and/or a rise in local temperature detected during the application.

1. Introduction
Mechanical vibrations are increasingly used in Physical and Rehabilitation Medicine clinical practice, for the treatment of specific diseases and in sport rehabilitation. Indeed, the application of mechanical vibration can induce adaptive responses on the human body, as it can stimulate both neuromuscular and skeletal systems [1][2][3]. Local vibration (LV) application allows to apply and act only where needed, focusing the treatment on the selected body segment. This is of great importance, as it should be noted that not always the application of vibration is shown to have positive effects on our body [4]. However, reduced periods of exposure and specific oscillation frequencies, don’t entail any negative metabolic effect but instead induce positive body adaptations. The effectiveness of these applications is widely described in numerous publications but the etiology, i.e. how the vibration application is able to elicit such responses
in the human body, still remains partially unknown. The intention of this work is to investigate the metabolic effects induced by vibration treatment, in particular those produced during a local vibration treatment using an experimental device dedicated to LV. In order to detect these effects, a device for monitoring muscle oxygenation, the oximeter, has been used. This oximeter, using near infrared spectroscopic technique (NIRS, Near InfraRed Spectroscopy), is able to determine the concentration of total haemoglobin \( [\text{THC}] \), oxygenate haemoglobin \( [\text{HbO}_2] \), deoxygenate haemoglobin \( [\text{Hb}] \) and oxygen saturation (\% ox) in the tissues [5]. The aim of the study is to understand the metabolic effect of vibration on the muscle by studying and analyzing, through an oximetric analysis, the changes of haemoglobin concentrations and oxygen saturation, during LV treatment.

2. Materials and Methods

2.1. Local Vibration Device

In this work we decided to study LV application on a single muscle, the right brachial bicep muscle. For the application of local mechanical vibrations we used an experimental device, designed and optimized by the Medical Engineering Service of the Tor Vergata University Hospital in Rome, in collaboration with the Physical and Rehabilitation Medicine Chair of the Tor Vergata University in Rome and the BoscoSystemLab s.r.l. company (Fig. 1). This device has a digital control panel through which specific parameters, such as time and frequency, can be set. The console is connected to a handpiece in which a motor and an eccentric mass are placed. The vibration is produced by the rotation of this mass activated by the motor. The vibration is delivered onto the area of interest through an adapter, designed to exactly adhere to the body area treated. In addition, this device is provided with a fastening system, therefore has the advantage of being applied without the operator’s support during treatment [6]. This avoids the transmission of vibrations to the operator, which, in the long run, could be harmful to the operator himself. The vibration treatment protocol used in this study is based on a training scheme developed by the Physical Medicine and Rehabilitation Department of the Tor Vergata University Hospital but has been slightly revised since it was performed on healthy subject. The treatment involved a series of three repetitions of vibration at 35Hz for 30 seconds and a repetition of 35Hz for one minute, with 60 seconds pause between each repetition.

2.2. NIRS and human tissue

The oximeter allows the detection of \([\text{THC}], [\text{HbO}_2], [\text{Hb}]\) and \% ox in the human tissues using NIRS, a spectroscopic method that works in the near infrared region of the electromagnetic spectrum. This device is based on the theory of photon migration through highly scattering media, such as the human tissue, and works injecting near-infrared light into the tissue at different wavelengths. The propagation of light inside biological tissues can be described in terms of photons’ flow [7]. While traveling inside tissues, photons can undergo a number of different processes, such as absorption, elastic scattering, inelastic scattering and fluorescence. The main absorbers of NIR light in blood-perfused tissues are metal complex chromophores, such as haemoglobin, bilirubin, cytochrome and water. Therefore generally oximeters operate
in wavelengths between 700 and 850nm, where the absorption spectra of \( Hb \) and \( HbO_2 \) are maximally separated and there is minimal overlap with \( H_2O \). An oximeter is made of a light source, a detector and a dispersive element that allows to record the intensity at different wavelengths. Measurements are generally obtained using a photometer that, by means of laser diodes or LED, generates light in the infrared spectrum. The light is emitted from a particular optode, which is connected to the instrument through an optical fiber. The light, scattered by the tissues, is then detected by a second optical fiber and is captured by a photomultiplier or a photodiode. Available devices use reflectance-mode NIRS, in which receiving optodes are placed ipsilateral to the transmitter. These optodes exploit the fact that photons transmitted through a sphere will traverse an elliptical path, in which the mean depth of penetration is proportional to the transmitter and receiver optode separation. Numerous studies have shown that the maximum distance between source and detector is about 3.5-4cm, allowing the photons to penetrate into the biological tissue up to a maximum depth of 5cm. Measurement of tissue oxygen saturation and tissue \( Hb \) content is determined by the difference in intensity between the transmitted and received light as described by the Beer-Lambert Law.

2.3. Systemic Analysis

In a preliminary stage we investigated the effects induced by LV application, by measuring blood pressure, heart rate, oxygen saturation and temperature. These parameters were measured in 10 subjects and their variations were examined during the vibration treatment. The vibrating device was placed on the right brachial bicep at 4cm from the inner fold of the elbow flexion. For the simultaneous measurements of pressure, frequency and saturation, a multiparametric monitor for vital signs was used (Mod. CS242 Propaq Welch Allyn). The parameters were recorded at different times: at rest, during each vibration and finally after 2 minutes of rest. For the temperature measurement a digital thermometer (Thermometer Fluke 52 II) provided of two thermocouples was used. These allowed monitoring of temperature changes close to the area subject to vibration. The first probe was placed distally, at 2cm from the inner fold of the elbow flexion, while the second probe was placed at 2cm from the vibrating device. This thermometer allows the measurement and storage of instantaneous temperature values in a defined period and calculates the maximum, the minimum and the mean value in that interval. The protocol used to measure temperature is the following: the instantaneous temperature was measured at rest, before and after the positioning of the device on the arm, to detect the possible temperature changes caused by the presence of the fastening system; during each vibration the thermometer was set in order to provide the minimum, maximum and mean values recorded during the treatment; the instantaneous temperature was measured after 30s of rest time; the instantaneous temperatures were measured at the end of the treatment after the first and second minute of rest and after removing the device.

2.4. Metabolic Analysis

In order to detect the metabolic effects induced by LV on the muscle, a tissue oximeter was used (ISS Model 96208: Two Channel, ISS Inc., Champaign, IL USA). This oximeter is based on the frequency domain resolved spectroscopy with the "multidistance" approach [8]. The device works by injecting near-infrared light into the tissue at two different wavelengths. Light sources are made of 8 laser diodes, four of which emit at 750nm and the other four at 830nm [9]. These are coupled to optical fibers of 400\( \mu m \) inner diameter, which guide the light in the measurement probe that is applied directly to the skin of the patient. The emitted light propagates in the tissue, where it is in part absorbed and in part scattered and backscattered. The latter is then collected by a bundle of optical fibers, of 3mm inside diameter, and sent to a photomultiplier tube. The source and the detector fibers are arranged in the probe so that the instrument can acquire data on the sample surface at four known distances between source and detector with a
constant increase of about 0.5 cm, starting from a minimum of 2 to a maximum of 4 cm (2, 2.5, 3, and 3.5 cm, respectively) (Fig. 2). Light is modulated at a frequency of 110 MHz to allow the collected light phase and modulation measurements. From these raw data the absorption and scattering coefficients of the medium are determined. Once these coefficients are determined, the assumption that haemoglobin is the only significant absorber is applied, so \([HbO_2]\) and \([Hb]\) are calculated [10]. Therefore analyzing these amounts during the treatment, we believed it was possible to obtain information about the metabolic activity of the muscle. For this purpose, in order to observe the presence or absence of these concentrations’ variations, the oximeter probe was placed in proximity of the muscle exposed to LV. The measurements were carried out in 5 different subjects. To record parameters, a sampling of 1s rate was performed. In this case, the measurement protocol was modified: four vibrations were applied at 35 Hz, lasting 30s for the first three repetitions and 60s for the fourth. Each rest periods was longer than 60s in order to allow the concentrations trends to stabilize at a constant value.

3. Results and Discussion
The data obtained from measurements of pressure, frequency and oxygen saturation, were analyzed using a computation software. From these results it was inferred that while the saturation remained roughly constant during the entire proceeding, the blood pressure and the heart rate values changed but not significantly (Fig. 3). These data confirmed that the effects induced by LV application are actually localized. For what concerns the temperature an increase of the values was noted, that in some subjects reached a maximum of 3°C. On average, however, the increase detected by the distal probe T1 was 1.5°C, while the proximal probe, T2, increase was 2.5°C. From the analysis performed by the oximeter, on the data obtained in each subject and recorded every second, after performing a regression with Matlab program, it was possible to observe a definite trend for each parameter. Fig. 4 shows these trends and their interpolations obtained with the measurements in one of the five examined subjects. In this figure it can be observed how \([THC]\) and \([HbO_2]\) have a very similar trend, particularly after the first two LV applications. These concentrations increased up to a maximum value and then remained constant. Less evident is the increase of the % ox and the \([Hb]\) decrease. The concentration values growth of the first three parameters, in all 5 subjects, was confirmed with a statistical analysis, the one-tailed t-test, with a significance level of 0.05. This test allowed to compare the normalized difference between the maximum value assumed by each parameter and its initial value in each subject, with a baseline vector. This test confirmed the statistical significant increase of \([THC]\), \([HbO_2]\) and % ox, \((p < 0.05)\), as observed on the trend of regression, finding a high probability of growth. As regard to \([Hb]\), a two-tailed t-test with 0.05 significance level was used. A statistical significant variation of \([Hb]\) with respect to a baseline vector has been demonstrated \((p < 0.05)\).

4. Conclusion
The analysis performed on the pressure, frequency and saturation values recorded during vibration treatment, showed that, although a small variation of these parameters is present, at the end of the treatment similar initials values are reached. Therefore absence of a systemic
response induced by the LV application can be affirmed. Moreover, through this preliminary analysis we showed that LV can induce a localized effect leading to an increase of temperature in the treated area. A tissue oximeter was used during LV application to determine haemoglobin concentrations in the tissue analyzed. Through NIRS it was possible to confirm the presence of muscle metabolic activity and identify the concentration variations of the two forms of haemoglobin. This monitoring has allowed to identify in real time the presence of metabolic changes in the muscles during the application of LV. In particular, the trends have shown an increase in oxygenated haemoglobin, that can be justified by an increased blood flow caused by vasodilatation. This could be caused by a muscle activity increase and/or by a local temperature raise, actually encountered during the application of vibration. The next step would be to evaluate if the local temperature increase could have influenced the monitoring carried out with the tissue oximeter. Hence, haemoglobin concentrations could be measured, using the same oximeter, in absence of vibration, inducing an artificial temperature rise in the brachial biceps muscle, equal to the temperature change detected.

References

[1] Trombetta C, Abundo P, Rosato N and Foti C 2011 Application of local vibrations in delayed and non-union fractures: case study. J. Phys. Conf. Series 280 (1)
[2] Ljoka C, Della Bella G, Carcelli L, Maugeri E, Giordani L and Foti C 2006 Preliminary study on the effect of the vibratory therapeutic exercise of non-union fracture. Europa Medicophysica, 42 (3)
[3] Goodship AE, Lawes TJ and Rubin CT 2009 Low-magnitude high-frequency mechanical signals accelerate and augment endochondral bone repair: preliminary evidence of efficacy. Journal of Orthopaedic Research
[4] Abundo P, Trombetta C, Foti C and Rosato N 2011 Production, delivery and application of vibration energy in healthcare. J. Phys, Conf. Series 280 (1)
[5] Ferrari M, Mottola L and Quaresima V 2004 Principles, techniques, and limitations of near infrared spectroscopy. Can. J. Appl. Physiol., 29 (4) pp 463–487
[6] Trombetta C, Abundo P, Felici A, Foti C and Rosato N 2011 Development of a device for local vibration application in non-union fractures. Conference Proceedings, IEEE Interactive Electronic Library pp 593–596
[7] Taroni P, Pifferi A, Torricelli A, Comelli D and Cubeddu R 2003 In vivo absorption and scattering spectroscopy of biological tissues Photochem. Photobiol. Sci. 2 pp 124–9
[8] Fantini S, Franceschini M A, Mayer J S, Walker S A, Barbieri B and Gratton E 1995 Frequency-domain multichannel optical detector for non-invasive tissue spectroscopy and oximetry Opt. Eng. 34 (1) pp 32–42
[9] Delpy D T and Cope M 1997 Quantification in tissue near-infrared spectroscopy Phil. Trans. R. Soc. Lond. B 352 pp 649–59
[10] Vernieri F, Tibuzzi F, Pasqualetti P, Rosato N, Passarelli F, Rossini P M and Silvestrini M 2004 Transcranial Doppler and Near-Infrared Spectroscopy Can Evaluate the Hemodynamic Effect of Carotid Artery Occlusion Stroke 35 pp 64–70