The effects of ultrasound and shockwave treatment on muscle regional oxygen saturation using near-infrared spectroscopy

Anna Lubkowska1✉, Aleksandra Radecka1, Miłosz Parchimowicz1, Iwona Bryczkowska1, Monika Chudecka2

1Pomorski Uniwersytet Medyczny w Szczecinie, Zakład Diagnostyki Funkcjonalnej i Medycyny Fizykalnej, ul. Żołnierska 54, 71-210 Szczecin
Pomeranian Medical University in Szczecin, Department of Functional Diagnostics and Physical Medicine
2Univarsytet Szczeciński, Katedra Anatomii Funkcjonalnej Człowieka i Biometrii, ul. Cukrowa 12, 71-004 Szczecin
University of Szczecin, Department of Human Functional Anatomy and Biometry
✉ anna.lubkowska@pum.edu.pl

INTRODUCTION

Pressure waves (or sound waves) have been used in medicine for many years as both diagnostic and therapeutic tool [1, 2]. The influence of pressure waves on biological tissues relate primarily to mechanical production of molecular vibrations. Mechanical waves cause direct effects in the form of increased cellular metabolism, transmembrane diffusion processes, and stimulation of microcirculation [3, 4]. Mechanical vibrations...
The effects of ultrasound and shockwave treatment on muscle regional oxygen saturation using near-infrared spectroscopy

The study was conducted at the Department of Functional Diagnostics and Physical Medicine (DFDPM), Pomeranian Medical University in Szczecin (PMU) in Poland. Each of the participants signed a written informed consent before taking part in the study according to the Declaration of Helsinki. The study was approved by the local Ethics Committee of the PMU (protocol number: KB-0012/36/13). The research was carried out under the projects of “Young Researchers” and “Statutory Activities” of the DFDPM, implemented in the period of 2014–2017. It was financed by the grants of the Ministry of Science and Higher Education obtained by Faculty of Health Sciences of the PMU (number of projects: MB-318-202/16/17; MB-318-06/15; WNoZ-318-01/S/13; WNoZ-318-02/S/13).

The study group consisted of 41 healthy volunteers (18 men and 23 women), aged 22–48 years. All participants had given their informed consent for participation in the research study. As a starting point, each of the study participants underwent a physical examination in order to identify possible contraindications for treatments.

Next, the subjects being qualified were randomly divided into 2 groups exposed to a single physiotherapy treatment:

**MATERIALS AND METHODS**

Next, the subjects being qualified were randomly divided into 2 groups exposed to a single physiotherapy treatment:
group 1 – to UST treatment, and group 2 – to rESWT treatment, respectively. The 2 groups did not differ statistically in terms of age and body weight. The characteristics of the study groups are presented in Table 1.

All treatments were performed to the same body region – the posterior part of the shoulder joint, about 2 cm below the scapular spine, i.e. to the infraspinatus muscle region. The study was performed at the same time of day for all participants (8–10 a.m.). Before the treatment, each of the study participants underwent a 20-minute acclimation in a seated position with the bare region of the body to be treated, then body surface temperature of the chosen region was measured and muscle tissue oxygenation (rSO2) with a NIRS using Sensmart-NIR SX-1000 (Nonin Medical B.V. Prins Hendrikklaan 26, 1075 BD Amsterdam, Netherlands) was estimated. For each subject, thermography was performed using a ThermoCAM SC500 thermal imaging camera (FLIR System, Inc., 16 Esquire Road, North Billerica, MA 01862.), providing long-wave imaging (75 to 13 μm) performance with a thermal sensitivity of 0.1°C. The value of skin emissivity was adopted as 0.98. The study was conducted according to standards set by the European Thermographic Association. The room (approximately 12 m² area), was closed, with a constant ambient temperature and humidity which were maintained at the same level during the measurement period. There were no draughts or influences of air conditioning. There was a low intensity natural lighting. A computerised image analysis system allowed determination of the measuring area of the body surface, with the mean surface temperature (Tmean) of the designated area being chosen for analysis. The measurement analysis used were Agema Report 5.4.1 and Agema Report Viewer 5.4. The measurement analysis was used to assess changes in regional muscle oxygen saturation of the stimulated tissue for which, as specified by manufacturer, haemoglobin oxygen saturation is measured at a depth of ~20 mm (S1) and ~12.5 mm (S2). It can be seen that mean baseline rSO2 differed, depending on the reading depth. For the depth of 20 mm (corresponding to the muscle tissue), the mean value was 71.26 ± 5.47% in group 1 and 70.17 ± 4.61% in group 2, whereas for the depth of 12.5 mm (corresponding to the adipose tissue), this value was 88.26 ± 2.89% and 87.17 ± 2.62%, respectively (Table 3 and 4). The mean surface temperature of the analysed regions was 34.04 ± 1.12°C in group 1 and 33.71 ± 0.62°C in group 2. There were no statistically significant differences between groups with respect to the baseline values of the analysed parameters. Table 3 summarises the results for the changes in surface temperature and regional oximetry in the group of subjects exposed to UST treatment, whereas Table 4 presents the results obtained in the group of subjects exposed to rESWT treatment. Following the application of ultrasound therapy, a significant but temporary decrease in the mean oxygen saturation was observed immediately after and 15 min after the treatment at a depth of 12.5 mm (p < 0.05), and a sustained decrease in oxygen saturation 15–30 min after the treatment at a depth of 20 mm (p < 0.01). It should be noted that these changes were accompanied by a decrease in surface temperature of the analysed region (T1, T2, T3). When analysing the effects of mechanical energy in rESWT treatment, a transient decrease in surface temperature of the assessed region was found immediately after the treatment (p < 0.05), probably due to the mechanical friction intensively occurring during the wave application with the pneumatic method, and a significant decrease in oxygen saturation level not until 30 min after the treatment and only at a depth of 20 mm. Body surface temperature returned to the values comparable with baseline ones as early as 15 min after the treatment. In the treatment procedure, the option of coupling gel application

### Results

In the study being presented here, 2 types of sensors were used to assess changes in regional muscle oxygen saturation of the stimulated tissue for which, as specified by manufacturer, haemoglobin oxygen saturation is measured at a depth of ~20 mm (S1) and ~12.5 mm (S2). It can be seen that mean baseline rSO2 differed, depending on the reading depth. For the depth of 20 mm (corresponding to the muscle tissue), the mean value was 71.26 ± 5.47% in group 1 and 70.17 ± 4.61% in group 2, whereas for the depth of 12.5 mm (corresponding to the adipose tissue), this value was 88.26 ± 2.89% and 87.17 ± 2.62%, respectively (Table 3 and 4). The mean surface temperature of the analysed regions was 34.04 ± 1.12°C in group 1 and 33.71 ± 0.62°C in group 2. There were no statistically significant differences between groups with respect to the baseline values of the analysed parameters. Table 3 summarises the results for the changes in surface temperature and regional oximetry in the group of subjects exposed to UST treatment, whereas Table 4 presents the results obtained in the group of subjects exposed to rESWT treatment. Following the application of ultrasound therapy, a significant but temporary decrease in the mean oxygen saturation was observed immediately after and 15 min after the treatment at a depth of 12.5 mm (p < 0.05), and a sustained decrease in oxygen saturation 15–30 min after the treatment at a depth of 20 mm (p < 0.01). It should be noted that these changes were accompanied by a decrease in surface temperature of the analysed region (T1, T2, T3). When analysing the effects of mechanical energy in rESWT treatment, a transient decrease in surface temperature of the assessed region was found immediately after the treatment (p < 0.05), probably due to the mechanical friction intensively occurring during the wave application with the pneumatic method, and a significant decrease in oxygen saturation level not until 30 min after the treatment and only at a depth of 20 mm. Body surface temperature returned to the values comparable with baseline ones as early as 15 min after the treatment. In the treatment procedure, the option of coupling gel application

### Table 1. The characteristics of the study groups

<table>
<thead>
<tr>
<th>Treatment</th>
<th>UST</th>
<th>rESWT</th>
</tr>
</thead>
<tbody>
<tr>
<td>n (W = 14; M = 13)</td>
<td>n (W = 9; M = 5)</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>30.38 ±14.31</td>
<td>27.86 ±1.99</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>73.50 ±12.94</td>
<td>68.30 ±11.15</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>176.08 ±9.30</td>
<td>175.79 ±10.79</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.23 ±2.76</td>
<td>22.62 ±2.97</td>
</tr>
</tbody>
</table>

UST – ultrasound therapy; rESWT – radial extracorporeal shock wave therapy; W – women; M – men

### Table 2. The stimulation parameters

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>UST ultrasound therapy</td>
<td>Zimmer Physix 5 cm²</td>
</tr>
<tr>
<td>rESWT radial extracorporeal shock wave therapy</td>
<td>Rosetta 2.5–3.5 bar 2000 strokes frequency of 5–10 Hz</td>
</tr>
</tbody>
</table>

UST – ultrasound therapy; rESWT – radial extracorporeal shock wave therapy
Therapeutic pressure waves are often used to treat various musculoskeletal disorders as they are assumed to have thermal and mechanical effects on the target tissue resulting in an increased local metabolism and microcirculation, decreased pain and muscle tension, inhibition of muscle spasms, and accelerated healing [1, 9, 10, 11, 16, 19, 27]. At present, with the development and availability of precise research techniques in medicine, the assessment of possible therapeutic effect of physical therapy treatments including their dosage should be based on the objective findings of examination, supplemented by the evaluation of patient’s medical condition and his/her subjective feelings. It therefore seems important to search for a diagnostic method that allows for a realistic assessment of the improvement of tissue metabolism with oxygen [29, 30, 31]; in this case, NIRS seems to be a useful tool. It is a non-invasive technique that uses the differential absorption properties of haemoglobin to evaluate tissue oxygenation. This method has been used primarily as a research tool to assess dynamic changes in the status of tissue oxyhaemoglobin, deoxyhaemoglobin, total blood (haemoglobin) volume and the oxidation state of the copper moiety of mitochondrial cytochrome c oxidase (cytochrome a, a3) in brain and muscle [21, 24, 32]. The measurement is based on the relative ease with which near infrared light (700–1000 nm) penetrates through biological tissues, including bone, skin and muscle and allows for detection of changes in light-absorbing chromophores (haemoglobin, myoglobin and cytochrome c oxidase) in human in vivo [25, 33]. It is assumed that changes in haemoglobin and myoglobin oxygenation are an expression of the difference between the amount of oxygen delivered and consumed by tissues, an thus oxygenation are an expression of the difference between the amount of oxygen delivered and consumed by tissues, and thus prediction that result from diversity of indices and their interpretation that result from diversity of indices and their units being used in measuring equipment. In the case of the apparatus being used by us, this index is rSO2 expressed in %. Despite some limitations, many researchers believe that, due to the possibility of non-invasive and direct assessment of rSO2 in muscle capillary vessels, NIRS provides valuable information to evaluate the tissue condition [22, 26, 28, 32], owing to which NIRS can be an important tool for the objective assessment of physical training, planning of possible therapeutic strategies, and creation of rehabilitation protocols [24, 35]. We did not find, however, any reports on the use of NIRS to assess the effect of physical therapy treatments and therefore an attempt was made to evaluate the suitability of its application to assess the treatments, being by design of hyperaemic and trophic nature.

### DISCUSSION

Therapeutic pressure waves are often used to treat various musculoskeletal disorders as they are assumed to have thermal and mechanical effects on the target tissue resulting in an increased local metabolism and microcirculation, decreased pain and muscle tension, inhibition of muscle spasms, and accelerated healing [1, 9, 10, 11, 16, 19, 27]. At present, with the development and availability of precise research techniques in medicine, the assessment of possible therapeutic effect of physical therapy treatments including their dosage should be based on the objective findings of examination, supplemented by the evaluation of patient’s medical condition and his/her subjective feelings. It therefore seems important to search for a diagnostic method that allows for a realistic assessment of the improvement of tissue metabolism with oxygen [29, 30, 31]; in this case, NIRS seems to be a useful tool. It is a non-invasive technique that uses the differential absorption properties of haemoglobin to evaluate tissue oxygenation. This method has been used primarily as a research tool to assess dynamic changes in the status of tissue oxyhaemoglobin, deoxyhaemoglobin, total blood (haemoglobin) volume and the oxidation state of the copper moiety of mitochondrial cytochrome c oxidase (cytochrome a, a3) in brain and muscle [21, 24, 32]. The measurement is based on the relative ease with which near infrared light (700–1000 nm) penetrates through biological tissues, including bone, skin and muscle and allows for detection of changes in light-absorbing chromophores (haemoglobin, myoglobin and cytochrome c oxidase) in human in vivo [25, 33]. It is assumed that changes in haemoglobin and myoglobin oxygenation are an expression of the difference between the amount of oxygen delivered and consumed by tissues, an thus prediction that result from diversity of indices and their units being used in measuring equipment. In the case of the apparatus being used by us, this index is rSO2 expressed in %. Despite some limitations, many researchers believe that, due to the possibility of non-invasive and direct assessment of rSO2 in muscle capillary vessels, NIRS provides valuable information to evaluate the tissue condition [22, 26, 28, 32], owing to which NIRS can be an important tool for the objective assessment of physical training, planning of possible therapeutic strategies, and creation of rehabilitation protocols [24, 35]. We did not find, however, any reports on the use of NIRS to assess the effect of physical therapy treatments and therefore an attempt was made to evaluate the suitability of its application to assess the treatments, being by design of hyperaemic and trophic nature.

### TABLE 3. The results for the changes in surface temperature and regional oximetry in the group of subjects exposed to ultrasound therapy treatment

<table>
<thead>
<tr>
<th>n = 27</th>
<th>T₀</th>
<th>T₁</th>
<th>T₂</th>
<th>T₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>S₁ rSO₂ (%) (depth of measurement ~20 mm)</td>
<td>71.26 ±5.47</td>
<td>70.22 ±5.6</td>
<td>68.89 ±5.261</td>
<td>68.93 ±5.121</td>
</tr>
<tr>
<td>T mean (°C)</td>
<td>34.04 ±1.12</td>
<td>30.22 ±1.161</td>
<td>32.32 ±1.207</td>
<td>32.66 ±1.287</td>
</tr>
</tbody>
</table>

T₀ – before the treatment; T₁ – after the treatment; T₂ – 15 min after; T₃ – 30 min after; S₁ – sensor 1; S₂ – sensor 2; T mean – the mean surface temperature; ** T₀ p = 0.004629; * T₁ p = 0.04492; *** T₂ p = 0.00326

### TABLE 4. The results for the changes in surface temperature and regional oximetry in the group of subjects exposed to radial extracorporeal shock wave therapy treatment

<table>
<thead>
<tr>
<th>n = 14</th>
<th>T₀</th>
<th>T₁</th>
<th>T₂</th>
<th>T₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>S₁ rSO₂ (%) (depth of measurement ~20 mm)</td>
<td>70.17 ±4.61</td>
<td>71.25 ±4.73</td>
<td>72.83 ±6.6</td>
<td>69.5 ±4.71</td>
</tr>
<tr>
<td>S₂ rSO₂ (%) (depth of measurement ~12.5 mm)</td>
<td>87.17 ±2.62</td>
<td>88.08 ±4.12</td>
<td>87.42 ±5.93</td>
<td>88.08 ±3.23</td>
</tr>
<tr>
<td>T mean (°C)</td>
<td>33.71 ±0.62</td>
<td>34.58 ±2.061</td>
<td>34.21 ±0.81</td>
<td>33.82 ±0.75</td>
</tr>
</tbody>
</table>

T₀ – before the treatment; T₁ – after the treatment; T₂ – 15 min after; T₃ – 30 min after; S₁ – sensor 1; S₂ – sensor 2; T mean – the mean surface temperature; * p < 0.05; ** p < 0.01; *** p < 0.001
Some isolated evidence points out to the potential of using pressure waves in the treatment of many dysfunctions [1, 8, 12, 19, 36]; in practice, however, conclusive physiological improvement when using ultrasound and shockwave in controlled trials has not been definitively confirmed [1, 16, 37]. For this reason, the described therapeutic effect of pressure waves is sometimes based on hypotheses [4, 2, 37], and the obtained therapeutic effects are not fully explainable. In our study, we examined the ability of therapeutic sound waves to affect changes in haemoglobin and myoglobin oxidation in tissues at a depth of approximately 12.5–20 mm of the infraspinatus muscle region. When analysing the obtained results, it can be observed that significant changes with respect to regional oximetry were induced rapidly by the ultrasound treatment (Table 3), which can be confirmed by an immediate hyperaemic and hyperthermic effect of this physio-therapeutic procedure to deep tissues. The ability to measure local blood flow through a portion of tissue illuminated by NIRS light adds substantially to the information obtained on the adequacy of cellular oxygen provision. Blood flow is required to determine regional oxygen delivery and oxygen uptake [21, 24, 25]. These parameters may provide valuable insights into the basic mechanisms regulating microcirculatory O₂ transport and tissue O₂ utilisation in response to stimulation. Haemoglobin oxygen saturation (SaO₂) depends on: partial pressure of oxygen (Pao₂), 2,3-diphosphoglycerate level in erythrocytes, blood pH and temperature, and the relationship between SaO₂ and Pao₂ in the body at blood pH = 7.4 and temperature of 37°C is shown by the oxyhaemoglobin dissociation curve [12]. An increase in temperature promotes de-dissociation of oxygen from haemoglobin, which is seen in the NIRS image as a decrease in rS祐 value [10]. In the presented study, a significant decrease was observed in rS祐% value, continuing 30 min after the UST treatment.

Taking into account the biophysical effects of sound waves proven in literature, which include thermal and mechanical effects, the most likely explanation of the changes being shown is an increased temperature in the stimulated tissue region. Affecting the tissues, primary mechanical ultrasound energy is gradually absorbed and converted into kinetic energy, and finally into heat. The literature presents evidence for UST inducing a rise in tissue temperature [16, 38, 39]. The extent of tissue heating depends on a number of variable factors, e.g. consistency of tissues, angle of incidence, particularly at their borders, vibrational frequency, and primarily on the intensity (sound power) being applied [16, 39, 40, 41]. It is believed that the thermal effects of ultrasound treatment start when the value of sound power has exceeded 0.3 W/cm². The literature has documented the thermal effect of UST both in the context of animal and human studies. For example, the in vivo studies have shown the thermal effect of continuous therapeutic ultrasound inducing a temperature rise in the skin and deeper tissues and the fibrous capsule after treating a pig hip joint with ultrasounds. The dynamics of temperature rise depended to the greatest extent on ultrasound intensity; at 1.5–2.0 W/cm², the temperature increased only by 1°C, whereas there was a clear rise in fibrous capsule temperature, even by 2–4°C, at 25–3 W/cm² after 1–3 min of the treatment [39, 40, 41, 42]. The thermal effect of ultrasounds has been confirmed in human studies. Draper et al. [38] have applied similar levels in this study (Table 2), have shown a rise in gastrocnemius muscle temperature at a depth of 3 cm by 5°C after 10 min of ultrasound treatment with a continuous wave at 1.5 W/cm² and 1 MHz. The NIRS signal in human tissue is derived predominantly from the absorption of light by haemoglobin in small arterioles, capillaries and venules. According to our hypothesis, the heat generated during the treatment induces a reaction in the form of vasodilation and improvement of microcirculation, which increases the supply of oxygen to tissues, which – with simultaneous temperature rise and metabolism improvement – promotes its utilisation. According to the literature evidence, thermal and mechanical effects on the target tissue result in an increased local metabolism and microcirculation, promote re-perfusion and angiogenesis, reduce pain and muscle tension, inhibit muscle spasms, and accelerate healing [16, 27, 43]. Some researchers believe that these changes could account for the improved tissue repair which allegedly follows ultrasound therapy [44]. Taking into account the parameters of UST treatment being used in this study, based on the literature evidence, they confirm the thermal effect of this treatment and its beneficial consequences in the improvement of muscle tissue trophy. It seems that no skin hyperthermic effect being observed is mainly due to the fact that the operating frequency of ultrasound transducer was 0.8 MHz, which causes absorption of the sound wave energy at a depth of approximately 2–3 cm and, as is known, only the absorbed energy can induce the thermal effect and a rise in temperature [40, 44]. The above observations are consistent with the assumption that the UST treatment less overheats shallow tissues than the deeper ones, and obtaining the rise in skin temperature would require application of maximum ultrasound intensities of approximately 3 W/cm² [1, 8, 18, 40]. At the same time, the need for application of a couplant during the treatment and its potential impact on skin surface cooling should be emphasised; nonetheless, lower skin temperature values of the analysed regions continued 30 min after the treatment. This in turn points to the principle of opposite reaction of superficial vessels in relation to the deep ones that results from sustained overheating of tissues at a depth of 2–3 cm. The depth of UST wave absorption is affected not only by the frequency being used but also the structure of stimulated tissue. Ultrasound waves are poorly absorbed by fluids (e.g. blood), somewhat intensely by soft tissues (e.g. adipose tissue), and fully absorbed by the tissues that contain large amounts of structural proteins (e.g. nervous tissue, cartilaginous tissue, and bone tissue). In addition, at the border of tissues with extreme absorption properties (e.g. bone and muscle tissues), the sound absorption is significantly higher than at the border of soft tissues (e.g. adipose and muscle tissues) [5, 7, 8, 13, 14, 15]. The application of 2 sensor types allowed us to differentiate the measurement in relation to the reading depth to 10 and 12.5 mm. The region chosen by us is characterised by the adipose fat layer located subcutaneously, and next by...
the muscle tissue layer (being characterised by small inter-individual variation in terms of its thickness in non-training persons) and that of bone tissue of the infraspinous region. The border of the infraspinatus muscle and the infraspinous fossa is, as intended by the authors, the region with the highest absorption of UST waves, attributable at the same time to the depth of approximately 20 mm. When comparing the readings from 2 sensors, it can be seen that decreased oxygen saturation occurred immediately after the treatment at a depth of 12.5 mm, and only 15 min after the treatment at a depth of 20 mm, lasting there longer (Table 3). As with UST, the therapeutic use of ESWT refers primarily to the effect on soft tissues. The therapeutic mechanism of shockwave therapy in musculoskeletal problems and the specific biological effects on various tissues (bone, cartilage, tendon and ligament) are not fully understood; the biological effects of stimulation have been postulated to decrease pain and muscle tension, inhibit muscle spasms, reduce oedema, accelerate healing, and dissolve calcified fibroblasts [6, 19, 20]. Despite its frequent use, firm evidence on its effectiveness from randomized controlled trials seems to be lacking. Some research indicates that ESWT also improved microcirculation and increased metabolism [6]. In large animal and human studies, ESWT has demonstrated the capacity to promote angiogenesis, tissue perfusion, and improvement in angiogenesis endpoints [27]. For example, Notarnicola et al. [37] assessed the effects of extracorporeal shockwave therapy on tissue perfusion in the treatment of tendinopathies. This study shows a statistically significant reduction in tissue oxygen saturation measured by oximetry, which correlated with clinical improvement of patients. It is believed that reduced perfusion can regulate inflammatory process and offset increased vascularity [37]. In our study, we did not show any significant change in tissue oxygen saturation immediately after the single application of rESWT, nor to 30 min after it (Table 4). The studies cited above involve the application of full treatment series, which does not allow for a direct reference to the results being presented in them. No studies have been found that would evaluate the trophic effect with regional oximetry after the single application of rESWT. Additionally, we must notice, as has been shown, that pressure waves generated by rESWT cannot be called typical shockwaves because they lack the characteristic physical features of shockwaves [11]. The pressure wave produced by rESWT can reach speeds of about 20 m/s which is not high enough to generate a real shockwave [40, 41]. Most therapeutic effects of shockwave described in literature do not include their division into focused and radial ones but that they can potentially be the key to different observed stimulus effects. Radial extracorporeal shockwave therapy generates pressure waves by pneumatic or electromagnetic methods. Compressed air (or an electromagnetic field) is used to fire a projectile within a guiding tube that strikes a metal applicator placed on the patient’s skin. The projectile generates stress waves in the applicator that transmit as pressure waves to the tissue [45]. The pressure wave is transmitted to the patient’s skin through ultrasound gel and spreads as a spherical (radial) wave into the tissue. The energy is highest at the tip of the applicator and decreases peripherally by the square of the distance [36]. A significant increase in skin surface temperature immediately after the treatment is worth noting. The thermal effect is probably due to the intensive friction of applicator upon the skin surface and a noticeable post-treatment site reaction, resulting from superficial vasodilation. In addition, to avoid the effect of skin cooling, the rESWT treatment was performed without a couplant, which enhanced epidermal excoriation (Table 4). Perhaps, the demonstrated increase in temperature induced a decrease in oxygen saturation, similar to that in the UST treatment, but in the shallower tissues, however the NIRS sensor used by us does not read oxidation at a depth of less than 10 mm. Although both UST and rESWT are a type of procedure using mechanical waves, the changes induced in tissue pressure are of different nature. Each shockwave in shockwave therapy consists of an approximately 1 μs-long, positive (compressional) pulse followed by a longer (~5 μs), lower amplitude (rarefractional) pressure pulse, while UST produces multiple cycles of a single-frequency (usually 1–10 MHz) sinusoidal ultrasound wave. Ultrasound therapy is a more flexible technology, as it allows adjustment of all acoustic treatment parameters to optimise non-thermal bio-effects. Shockwave therapy only allows control of pulse repetition frequency and amplitude [27]. The presented differences can be important in terms of the potentially obtained trophic effect [27]. However, the mechanism of achieving the trophic effect mediated by UST or ESWT is still not explained and is an active area of research, especially with respect to a series of treatments.

To sum up, it is worth noting that although UST and rESWT belong to the same group of sound stimuli, their effects on metabolism, being measured by tissue oxygen saturation, does not proceed in the same way, most probably with the varied dynamics influence. Our initial hypothesis, i.e. the assumption of a potentially stronger trophic effect of rESWT for the muscle tissue, resulting from the more intense post-treatment reaction, can not be clearly confirmed. The magnitude and direction of changes in regional oximetry seem to be similar with respect to the level in the muscle tissue being recorded by a sensor from a depth of 20 mm although the effect occurs earlier following the application of UST (as early as after 15 min) than following rESWT (after 30 min). In addition, the application of UST induces a change in metabolism of the shallower tissues, which we did not observe after the application of rESWT.

CONCLUSIONS

The NIRS method is a useful tool to assess tissue oxygen saturation following the stimulation with mechanical waves. The single UST application decreases the value of oxygen saturation to 30 min after the treatment. The decrease in oxygen saturation is presumably the result of a temperature rise in the deeper tissues, promoting the de-dissociation of oxygen from haemoglobin and inducing the trophic effect. The single rESWT stimulation induces a change in oxygen saturation in
the 30-minute post-treatment period being assessed. Following the UST treatment, skin surface temperature of the stimulated region decreases, which the result of direct contact with a cool couplant. The rESWT treatment performed without acouplant exposure to low amounts of ultrasound energy does not improve soft tissue shoulder pathology: a systematic review. Phys Ther 2010;90(1):14-25. doi: 10.2522/ptj.20080272.


The effects of ultrasound and shockwave treatment on muscle regional oxygen saturation using near-infrared spectroscopy