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Comparison of skin surface temperatures after ultrasounds with use of paraffin oil and ultrasounds with use of gel

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Abstract Ultrasound heat effects are relatively easily perceived, being manifested by a tissue temperature rise resulting from intratissular conversion of mechanical energy into thermal one. The goal of the study reported was an evaluation of skin surface temperature distribution changes as a result of ultrasound therapy applied, with reference to the coupling medium used. The study involved 40 healthy students, with the mean age of the subjects in the study group being 20 years. All of the subjects were submitted to sonographic procedures with the use of two different coupling media, whilst skin surface temperature at the site was recorded by a thermovision camera. Sonographic beams were applied to the region of the left quadriceps femoris muscle by a dynamic method, using a continuous ultrasound wave of 0.5 W/cm^2 intensity and 1 MHz frequency. The area treated amounted to 300 cm^2, the sonotherapy lasted 10 min. Paraffin oil enhanced the thermal effects of the ultrasound signals applied, inducing mean tissue temperature rises. The mean temperature recorded immediately after ultrasound application was higher than the mean base temperature by 0.33 °C, rising to 0.62 °C at the 15th minute following the procedure, with $P < 0.05$. In contrast, application of gel led to considerable reductions in the mean temperatures of tissues submitted to ultrasound treatment: immediately after the sonographic procedure, tissue temperature decreased by 3.96 °C. On the basis of the results of the study conducted, it was concluded that the type of coupling medium applied influenced temperature levels within the treated area.

Keywords Sonotherapy · Thermovision · Paraffin oil · Ultrasound gel1

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Introduction

Physical medicine employs a number of physical factors for therapeutic, prophylactic and diagnostic purposes, including, amongst others, thermal, photochemical, electrokinetic and mechanical factors. Depending on the amount of energy applied, different reaction levels are induced in tissues. In recent years, the interest of researchers has increasingly been focused on the role of ultrasound in the human environment, with regard to both physical therapeutics and medical diagnostics [1]. Ultrasound (UD) is defined as mechanical vibrations of an elastic medium with a frequency of above 16 kHz. The most commonly applied frequency in sonotherapy varies from 800 kHz to 5 MHz [2, 3].

The mechanism by which a longitudinal ultrasound wave induces a biological effect is a complex and multilateral process, with various physical phenomena at its base. The thermal, mechanical and physicochemical actions of ultrasound induce a number of local controlling phenomena directly in front of the US probe, resulting in pain alleviation, enhancement of reconstructive processes and normalisation of immunological reactions. These phenomena occur as a result of improved blood flow and oxygenation in tissues, accelerated functioning of prosthetic enzyme groups, secretion of mediators and increased permeability of cellular and intracellular membranes [2]. The thermal effects of the ultrasound result from the transfer of mechanical energy to tissues, where it is converted into heat energy, increasing in this way the local tissue temperature. The physiological responses of the body to the ultrasound-related temperature rise include blood vessel dilation, increased blood flow in the skin, subcutaneous tissue and muscles, a raised pain sensation threshold, increased enzymatic activity and collagen stretching, variations in muscle tone and nervous conductivity. The heat generated is distributed by circulation and the elimination of its excess depends on blood flow rate [4, 5].

Thermal effects are relatively easily perceived, since they are manifested by increased tissue temperatures resulting from the intratissular transformation of mechanical energy into thermal. At present, sonotherapy is regarded as the most important therapeutic procedure with deep thermal effects [4, 6].

It is also worth emphasising that ultrasound, via its local effects, modifies a number of systemic phenomena. The receptors of feeling, in particular pain and temperature sensation receptors, are connected with the peripheral and central nervous systems, meaning that they may, when stimulated by the mechanical vibrations of the ultrasound beam—and depending on the manner of stimulation—induce controlling processes in targeted internal organs. The most distinctive reactions are perceived in circulation (blood flow changes in the skin or internal organs) and the nervous system (changes in conduction times or in nervous excitability threshold levels) [2].

During ultrasound wave applications, it is necessary to use a coupling substance because of the physical characteristics of the ultrasound wave. Wave reflection at the probe-air transition amounts to 99.9%, which means that even a very thin layer of air is an almost insurmountable obstacle for an ultrasound signal. To prevent energy losses and facilitate the transfer to tissues of vibrations generated in a transducer, it is necessary to couple its surface with the skin in the area treated.

The coupling substance should have an index of refraction in relation to tissue close to one, demonstrate a tissue-like wave propagation speed and provide an airtight barrier. Besides the above-mentioned features, an ideal coupling substance should remain chemically neutral to the skin, provide optimal wave transmission conditions, be spread easily, not allow absorption by the skin, prevent energy loss and be moderately liquid and odourless. These principles should apply equally to gel-like and oily substances, as well as to coupling media containing active medication, used in phonophoresis [1, 5, 7].

The goal of the study reported was an evaluation of skin surface temperature distribution as a result of applied sonotherapy, with regard to the type of coupling medium used.

Material and study methods

The study was performed at the Laboratory of Physiotherapy of the University School of Physical Education in Wrocław and involved 40 healthy students of the second year at the Physiotherapy Faculty, of which 13 subjects were female and 12 male. The mean age in the group was 20 years, with individual ages ranging from 19 to 24 years. All of the subjects gave their consent to participation in the study, while approval for the study was also issued on 7 April, 2009 by the Senate Commission for Research Ethics of the University School of Physical Education in Wrocław.

All of the study subjects received sonotherapy with the use of two different coupling media, whereas the temperature of the skin surface at the site was recorded by a thermovision camera. The ultrasound beams were applied to the region of the left quadriceps femoris muscle. The sonographic procedure was administered twice to each subject with a 7-day interval between applications, once with paraffin oil as the coupling substance and once with SONOBAX LTD. Producer of US gel, designed for ultrasound therapy applications. The procedures were performed according to the generally accepted method for the anterior surface of the left thigh. The ultrasound was generated by an IONOSON by Physiomed Germany with a 2.5 cm^2 probe. A dynamic method was applied, involving a continuous wave (filling factor 100%) of 0.5 W/cm^2 power and 1 MHz frequency. The area treated was always 300 cm^2, with the treatment lasting 10 min.

Skin surface temperature in the anterior area of the left thigh was recorded in each study subject by means of a Camera ThermoVision A 20 Flir System, supported by a PC with the Therma CAM Researcher 2.9 software package. Photographs were taken before administering sonotherapy, immediately afterwards and 15 min later.

The studies were performed in a room with an air temperature of 24–26 °C and a humidity of 50–70%, with no smoke, dust or vapours and with minimal circulation of air. A subject first adapted to the environmental temperature for 20 min, with the area of the body to be submitted to sonotherapy and later evaluations exposed in order to reduce psychogenic effects on temperature controlling processes in the body. None of the study participants had earlier been subjected to intensive physical exercises or physical procedures. The subject remained in a standing position, facing a thermovision camera and with the body area to be treated by ultrasound exposed. The distance between the skin surface and the front of the camera was maintained for each subject at two metres. The focus of the camera lens was targeted perpendicularly at the midpoint of area examined.

The database of images obtained numbered 240 thermograms and was recorded on a computer disc as graphic files in jpg format. An appropriate temperature scale (21–38 °C) was selected to enable proper interpretation of the thermograms. The material obtained underwent a computer analysis by the Therma CAM Researcher 2.9 program, with a rainbow colour scale used for graphic presentation of the thermograms, mainly for its large colour range, from cold colours (violet, blue and green) to warm (yellow, orange and red) [8].

To analyse the skin temperature within the region of the quadriceps femoris muscle, it was necessary to plot its contours onto a thermogram. See Fig. 1 for an example thermogram.

The results collected from measurements of each subject were input to a database before being subjected to a statistical analysis by means of the STATISTICA.PL program, calculating the mean, minimum and maximum temperature levels, standard deviation and coefficient of variation.

To determine the significance of mean temperature differences, analysis of variances (ANOVA) was performed, followed by Duncan's multiple range test, which is a continuation of ANOVA, in the event that significant changes are obtained. In the study reported, $P < 0.05$ was adopted as the level of statistical significance for test results and coefficient values [9].

Results

Based on the results and thermogram evaluations collected, Table 1 presents mean temperature values, standard deviations and coefficients of variation for tissues in the area studied before and after sonotherapy with the use of paraffin oil.

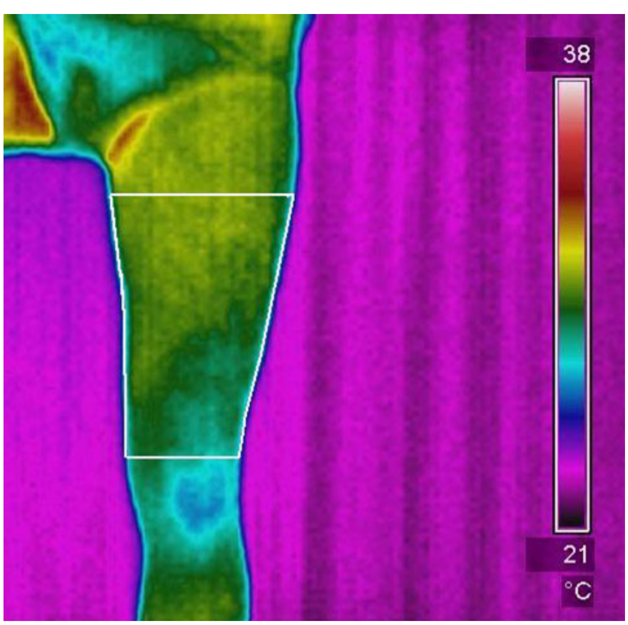

Fig. 1 Thermogram with temperature measurement area indicated

Table 1 Characteristics of data (paraffin oil)

Study stage	Mean temperature/°C	Standard deviation	Coefficient of variation
Before procedure	30.67	0.972	3.169
Immediately after procedure	31.00	0.922	2.976
15 min after procedure	31.29	1.000	3.195

Following a single provision of sonotherapy with paraffin oil used as a coupling medium, a rise in the mean temperature of the skin was noted in the area of the quadriceps femoris muscle over the measurement period. The mean skin temperature recorded immediately after the ultrasound procedure was 0.33 °C higher, the difference rising to 0.62 °C after 15 min. Statistical analysis using Duncan's test revealed statistically significant differences. Significance in relation to the mean base temperature was demonstrated by temperature differences both immediately after sonotherapy ($P = 0.017607$) and at the 15th minute following the procedure ($P = 0.000093$). Also, statistically significant was the change in the mean temperature immediately after sonotherapy compared to that 15 min from the procedure ($P = 0.03119$).

On the basis of the data presented above, it can be stated that 1 MHz sonotherapy with paraffin oil as a coupling medium resulted in a tissue temperature increase. Moreover, the temperature changes observed both immediately after the procedure and 15 min later demonstrated statistically significant changes (see Table 2).

Following this, the mean temperatures of the quadriceps femoris muscle were evaluated and compared after sonotherapy with gel as coupling medium. Table 3 presents mean temperature values, standard deviations and coefficients of variation for tissues in the area studied before and after sonotherapy with the use of gel.

Table 2 Duncan's test for mean temperatures before and after sonotherapy (paraffin oil)

Duncan's test approximate probability for post-hoc tests			
Mean temperature	Before procedure	Immediately after procedure	15 min after procedure
Before procedure			
Immediately after procedure	0.017607		
15 min after procedure	0.000093	0.03119	

Table 3 Characteristics of data (gel)

Study stage	Mean temperature/°C	Standard deviation	Coefficient of variation
Before procedure	31.34	1.076	3.43
Immediately after procedure	27.38	1.073	3.91
15 min after procedure	30.42	1.067	3.50

As a result of a single provision of sonotherapy with gel used as coupling medium, a significant drop in the mean temperature in relation to the mean base temperature was noted in the area measured immediately after the procedure. At the ultrasound target site, the mean skin surface temperature decreased on average by 3.96° immediately after the procedure. At the 15th minute following the procedure, the mean temperature of the area studied was still lower by 0.92 °C compared to the mean temperature before the procedure. Following a comparison of the mean skin surface temperatures measured immediately after the procedure and 15 min later, a significant temperature rise of 3.04 °C was noted, yet the temperature was still lower than the mean base temperature. Statistical analysis using Duncan's test revealed statistically significant differences. With regard to the mean base temperature, statistical significance was demonstrated by the changes both immediately after the procedure ($P = 0.000063$) and at the 15th minute ($P = 0.000117$), as presented in Table 4. In addition, the difference between the mean temperatures immediately after the procedure and those 15 min later revealed statistical significance ($P = 0.000117$).

A comparison of the mean temperature differences measured immediately after sonotherapy with the use of paraffin oil and gel (Table 5) was a further stage of the evaluation.

Having analysed the results obtained, it may be noted that a mean temperature rise immediately after the procedure occurred only with paraffin oil as the medium coupling the transducer with the treated surface. This increase amounted to 0.33 °C. In contrast, a drop occurred in mean temperature immediately after the procedure compared to the mean base temperature with gel as coupling medium. This drop in temperature amounted to 3.96 °C and can be regarded as significant. Duncan's test revealed statistically significant differences between the mean temperatures immediately after sonotherapy with the use of paraffin oil and gel ($P = 0.000045$).

Following this, the mean temperature differences recorded 15 min after the procedure were compared, for paraffin oil and gel (see Table 6).

An evaluation of the data in the table above demonstrates that the mean temperature of the area studied at the 15th minute after sonotherapy with gel was lower than the mean base temperature, although the difference obtained was not as high as for the mean temperature before and immediately after the procedure. In contrast, the use of paraffin oil in sonotherapy brought a reverse situation. The results obtained in the study indicated a tendency for the mean temperature to grow over the temperature measurement period, i.e. until 15 min after sonotherapy. Duncan's test demonstrated a statistically significant mean temperature difference 15 min after sonotherapy when using paraffin oil or gel ($P = 0.000059$).

On the basis of the results obtained, it has been confirmed that the mean temperature of tissues in the area treated with ultrasound depends on the coupling medium applied during sonotherapy. Paraffin oil enhanced the thermal effects of the ultrasound applied, causing an increase in mean tissue temperature. In contrast, the use of gel considerably reduced the mean temperature of tissues submitted to sonotherapy.

Table 4 *P* values in Duncan's test for the mean temperatures, both before and after sonotherapy with the use of gel

Duncan's test approximate probability for post-hoc tests			
Mean temperature	Before procedure	Immediately after procedure	15 min after procedure
Before procedure			
Immediately after procedure	0.000063		
15 min after procedure	0.000117	0.000117	

Table 5 A comparison of the differences between the mean temperatures before and after sonotherapy

Coupling medium type	Mean temperature before procedure/°C	Mean temperature immediately after procedure/°C	Difference between the mean temperatures*
Paraffin oil	30.67	31.00	**0.33**
Gel	31.34	27.38	**−3.96**

*$P < 0.05$

Table 6 A comparison of the differences between the mean temperatures before sonotherapy and 15 min afterwards

Type of coupling substance	Mean temperature before procedure/°C	Mean temperature 15 min after procedure/°C	Difference between the mean temperatures*
Paraffin oil	30.67	31.29	**0.62**
Gel	31.34	30.42	**−0.92**

*$P < 0.05$

Discussion

The internal study performed allows it to be stated that the use of paraffin oil as a coupling medium in sonotherapy induces a significant and long-lasting heat effect at the ultrasound application site. In contrast, the use of gel as a coupling medium results in an effect the reverse of this, manifested as a considerable drop in the mean tissue temperature in the area of the quadriceps femoris muscleimmediately after the procedure.

Following the study reported, it may be stated that the generation of the heat effect, and therefore, the provision of efficient ultrasound wave transmission from transducer to target tissue, also depends on the type of coupling medium applied [7].

By reviewing the available literature, numerous reports may be found concerning the thermal effects of ultrasound, yet only some of them approach the issue of the coupling medium used during sonotherapy. The effects of coupling media on thermal tissue changes induced by ultrasound waves were studied by Lehman et al. [6, 10]. Basing on their own research, they noted that the highest temperature following ultrasound in the tissues closest to the bone was obtained when using as a coupling medium degassed water at temperature of 24 °C. On the other hand, using universal oil of the same temperature as a coupling medium, they obtained the highest temperature in superficial tissues. The researchers explained this phenomenon by the better heat conductivity and higher specific heat of water.

Williams, having submitted various tissue preparations to 1 MHz ultrasound with a continuous wave of 1 W/cm^2, obtained a mean temperature rise in tissues of 0.86 °C per minute. The researcher did not, however, specify which type of coupling medium had been used during the sonographic procedure [11, 12].

In Polish and foreign publications, reports may be found of several clinical trials indicating a heat effect induced by ultrasound.

Holcom analysed the effects of superficial tissue warming on temperature rise and fall in the triceps surae muscle, submitting it to a continuous ultrasound wave of 1 MHz frequency and 2 W/cm^2 intensity. Temperature was measured at a depth of 3.75 cm below the surface of the skin using thermistor (temperature-sensitive resistor) sensors. To avoid wave dissipation, a gel was used as the coupling medium. On the basis of the results obtained, a temperature increase of 4 $\pm$ 0.21 °C was noted in the event of an earlier warming of the treated area, while the temperature rose by 3 $\pm$ 0.22 °C with regard to the base temperature without prior warming of the treated area. However, the temperature decrease recorded 15 min after conclusion of the procedure was in both cases comparable, amounting to approximately 2 °C [13].

Burr et al. applied thermistor sensors in their research to measure temperature changes under the influence of sonotherapy in the interior structures of the gastrocnemius muscle (at a depth of more than 3 cm). They used a continuous ultrasound wave of 1 MHz frequency and 2.4–1.0 W/cm^2 and 1.5 W/cm^2 intensity. However, a considerable intramuscular temperature increase of 3.22 $\pm$ 1.25 °C was significant for the researchers. This increase occurred during the 2.5 min of the procedure for the power density of 2.4 W/cm^2, in comparison with the dose of 1.5 W/cm^2, where temperature rose by 1.68 $\pm$ 0.72 °C [14].

The thermal effects of ultrasound were also confirmed by Draper et al. and Chan et al. No information was, however, included in the reports of either researcher on the type of coupling medium used during ultrasound procedures [11, 15, 16].

In turn, Szymańska et al. attempted to determine temperature difference on the skin surface following sonotherapy with a continuous and pulsed wave. A pyrometer was used for temperature measurements at the ultrasound application site and an ultrasound wave of 0.5 W/cm^2 power density was generated with 3.2 MHz frequency, with the filling coefficient set to the level of 1:5. On the basis of a single sonotherapy treatment with either continuous or pulsed wave, a rise in skin temperature was noted in relation to the base temperature, increasing until the end of the measurement period. Temperature increases were, however, much higher for the continuous than the pulsed wave, amounting to 0.22 °C immediately after the procedure, 0.5 °C after 15 min and 0.84 °C 30 min after the procedure. However, the author does not provide any information on the type of coupling medium used during sonotherapy [4].

Temperature monitoring is one of the oldest means of human health evaluation. There are many different methods of temperature measurement, although thermovision is currently attracting more and more interest. This contactless method allows for precise recording of temperature distribution on the skin surface or in subcutaneous tissue to a depth of a few millimetres. A thermovision camera records temperature variation dynamics, while thermograms provide significant diagnostic data. Thermovison technology has been widely used in modern medicine and is a valuable complement to diagnostic procedures currently applied [8, 17, 18].

Holcomb and Burr, using gel as the contact medium, noted a tissue temperature increase due to ultrasound effects of as much as 3 °C immediately after the procedure in comparison with the base temperature. Such results, so different from the results obtained in this study (where a mean temperature drop of 3.96 °C in relation to the base temperature was recorded immediately after the procedure) may have been a consequence of the measurement method applied and, in particular, may have been related to the depth at which temperature was measured [13, 14].

The effects of water in which sonotherapy is performed on surface temperature variations in ultrasound-treated tissues are slightly similar to those of paraffin oil. This has been described thoroughly in the research of Taradaj et al., which indicated that the tissue temperature rise was at its highest immediately after the procedure, before gradually falling until the end of the measurement period. The results obtained are very reliable as temperature was recorded by a thermovision camera. Juxtaposing the studies of Taradaj et al. with the results described in this report, it may be stated that the ultrasound thermal effect, enhanced by paraffin oil, is of a long-lasting character, as the mean temperature of tissues gradually rises with each subsequent measurement. In contrast, in the case of sonotherapy performed in water, the heat effect is rather short [18]. Lehman et al. also confirmed that sonotherapy in water causes a tissue temperature increase [10].

Even the most frequently found publications on the issue in question provide no information on the type of coupling medium used during the ultrasound procedure. Gieremek et al. stated that immediately after the ultrasound procedure the temperature of the targeted area was lower in comparison to the base temperature. Based on this rather laconic statement, it may only be presumed that gel was used in their research as the coupling medium in sonotherapeutic procedures [19]. In turn, in the studies by Szymańska et al., a tissue surface temperature increase was recorded immediately after sonotherapy. This temperature demonstrated a tendency to increase over time, which may suggest the use of paraffin oil as the coupling substance. In addition, the results of the research by Łukowicz et al. may indicate that paraffin oil was used as the contact medium during ultrasound treatment procedures. No data have been found in the available literature which would confirm unequivocally which type of coupling medium affects surface temperature distribution in ultrasound therapy. The goals of further studies will probably include precise determination of this relationship, with clear indication of which contact substance is most effective for heat effect enhancement in ultrasound therapy.

Despite the fact that thermovision is now one of the safest, most accurate and valuable methods of temperature measurement, there have been few studies on sonotherapy with the use of thermovision as a tool for recording the surface temperature of human skin. The growing interest in visual thermography and sonotherapy, which is a promising physical method, provides a firm basis for the assumption that further development in science will prompt many new studies on ultrasound therapy with thermovisual evaluation. Technical progress should enable the use of ever more accurate research methods able to provide higher reliability in the results obtained.

Conclusions

1. A single sonotherapeutic procedure with paraffin oil as the coupling medium increases tissue temperature at the ultrasound application site.
2. A single sonotherapeutic procedure with gel as the coupling medium decreases tissue temperature at the ultrasound application site.
3. Juxtaposing the results of sonotherapeutic procedures using paraffin oil and gel as coupling media, it may clearly be seen that tissue temperature changes at the ultrasound application site depending on the type of coupling substance used.

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