

Application of thermovision in assessment of superficial tissue temperature changes under the influence of 1 MHz and 3 MHz ultrasounds wave

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Abstract Ultrasound wave is a physical method commonly used in the rehabilitation process. Biological effects of ultrasound wave are complex, and they have been subject of several studies for many years. It is assumed that ultrasound wave causes an increase in tissue temperature; however, some study results stay in opposition to this statement. Thermal imaging is a method that helps to determine, in a precise way, the temperature distribution of the tested body surface area, which allows us to verify whether ultrasound waves always have thermal effects. The aim of the study was to evaluate the differences in temperature distribution depicted by thermal imaging, after the use of ultrasonic waves with two different values of frequency (1 and 3 MHz) in the area of Achilles tendon. The study involved 50 healthy students group in which there were 28 women and 22 men. The average age in the group was 20.54 years (± 1.09). All study participants underwent ultrasound treatment with two different values of frequency. Skin temperature of the tested area was recorded with the use of thermographic camera. Ultrasound wave was applied to the area of Achilles tendon. Each person had the procedure performed twice with a seven-day time interval. There were ultrasonic waves with a frequency of 1 MHz applied one time and then ultrasonic wave with a frequency of 3 MHz applied once for the second time. Paraffin oil was used as a coupling medium. The result of Student's *t* test showed a statistically significant difference in mean temperature values measured immediately after treatment (3.3341) and 5 min after the treatment (2.6037) for a frequency of 3 and 1 MHz. A comparison of

temperature values for both frequencies 10 min after the treatment and 15 min after the treatment was not statistically relevant. The results of the studies indicate that only ultrasonic treatment at a frequency of 3 MHz has influence on an increase of surface temperature.

Keywords Thermal imaging · Thermovision · Sonotherapy · Treatment parameters

Introduction

Many years of application of ultrasonic wave have led to the development of precise methods that guarantee desired therapeutic, as well as diagnostic effects. Scientific and technological progress enabled common use of ultrasounds in physical medicine, what is more, its use for diagnostic purposes opened up completely new prospects for the future [1–4].

Biological action of ultrasound wave in tissues combines thermal, mechanical, and physicochemical effects. It is based not only on local changes (primary effect), but also on general responses (secondary effect). Through local action, ultrasound wave causes a range of systemic phenomena. Sensory, pain, and temperature receptors, located in the field of mechanical vibrations, are connected to peripheral and central nervous system and, depending on the method of agitation, may result in the appropriate regulatory phenomenon in internal organs. The most visible changes are cardiovascular responses (changes in blood flow not only in the skin but also in internal organs) and changes in the nervous system (changes in the time of conduction or in the threshold of excitability of nerves). Produced heat causes dilatation of blood vessels in tissues which is linked to better oxygenation, nutrition, local acceleration of metabolism, and removal of waste products.

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Ultrasounds cause changes in the colloidal proteins and increase the extensibility of collagen fibers [5–7].

For many researchers and clinicians, overheating is the most important of all types of biological effects of ultrasound wave used in physical therapy. Thermal effect is often called the ultrasound heat and the operation itself belongs to the field of thermotherapy. The heat generated in the result of the ultrasound wave treatment positively affects the muscles, cartilage, nervous system, and blood. Warming of the tissues causes increase of the threshold of pain, muscle relaxation, and changes in nerve conduction. A secondary effect is the increase of the kinetic energy, which leads to increased enzyme activity in the treated area.

Currently, ultrasound wave occupies a permanent place in physiotherapy and medicine. They are used, among others, in the treatment of neuralgia, osteoarthritis, wounds, sports injuries, and in the diagnosis of internal diseases [1, 3, 8–11].

Absorption of ultrasonic energy depends on the frequency and characteristics of the medium. The greatest heat absorbing ability have gases, smaller ability—liquids and the smallest—elastic solids. The ability of a medium to absorb ultrasonic energy is expressed in absorption coefficient. It determines the fact what part of the ultrasonic energy is converted into heat, penetrating into the material. The absorption coefficient of a given substance depends on the frequency. The penetration depth of the waves, and thereby also the level of the tissue heat can be controlled, to certain extent, by the choice of the operating frequency of the transducer. In accordance with existing results, ultrasound at a frequency of 1 MHz definitely causes deeper penetration than a frequency of 3 MHz. Therefore, in order to obtain the effect of a warm surface of the penetrated area, ultrasound of lower frequencies is used [12–15].

Thermal imaging is a method that allows us for precise registration of the temperature distribution on the surface of a body, therefore, more and more studies of temperature change are based on the analysis of thermal images. Thermal imaging can be used to assess the effects of some physical treatments, which usually change the temperature of the skin. As a non-invasive method, thermography is used in the field of diagnosis and is a valuable complement of routinely used diagnostic methods which are not always indifferent to the health of the patient [16–22].

The aim of the study was to evaluate the differences in temperature distribution, depicted by thermal imaging, after the use of ultrasonic waves with two different values of frequency (1 and 3 MHz) in the area of the Achilles tendon.

Research methods and materials

The study was conducted at the Laboratory of Physical Therapy in the University School of Physical Education in

Wrocław. The study involved 50 healthy students group consisting of 28 women and 22 men of the second year of the Faculty of Physiotherapy. The average age of the group was 20.54 years (± 1.09) with the age of the youngest person—19 years, whereas the oldest—24 years. All persons gave their consent to participate in the study experiment. The study was approved by the Senate of Ethics Committee for Scientific Research, University School of Physical Education in Wrocław on 19.03.2012.

All study participants underwent ultrasound wave treatment with the use of two different values of frequency, while the temperature of the tested skin surface was recorded with thermal imager. Ultrasound wave was applied to the area of Achilles tendon. Each person had the procedure performed twice with a 7-day time interval. Once the treatment included the use of ultrasonic waves with a frequency of 1 MHz and once with the use of ultrasonic wave with a frequency of 3 MHz. The coupling material used in the treatment was paraffin oil.

Treatments were performed on the posterior surface of the lower leg in accordance with generally accepted methodology. Ultrasounds were generated by the SONICATOR 740 ultrasound wave device with the applicator head of 5 cm². The dynamic, continuous wave (duty cycle amounted to 100 %) with a power of W/cm² was applied, whereas the operating time was 10 min. The frequency was set at 1 and 3 MHz not only in the first treatment, but also after 7 days break in the second treatment.

All patients' skin temperature of the rear surface of the right lower leg was registered with ThermoVisionA20 M infrared camera, interacting with a personal computer equipped with ThermaCAMResearcher2.9 program. Photos were taken not only before, but also immediately after the ultrasound treatment and 5, 10, and 15 min after the therapy.

The study experiment took place in a room with a temperature of 24–26 degrees Celsius with humidity of 50–70 %, without smoke, dust, vapors, and minimum air movement in the room. The study participants had to adapt to the environment temperature with the exposed surface of the tested body part for 20 min, in order to reduce the influence of psychogenic thermoregulation processes. None of the people participating in the study had not previously been subjected to intense effort or physical treatments. The person examined was placed in a standing position, with the back toward the infrared camera with the exposed surface of the tested body part. The distance between the participants from the front of the camera retained the same in each trial and equaled two meters. The focal length of the camera lens was directed perpendicular to the center of the tested area.

Photo database consisted of 250 thermal images, which were recorded on a computer disk as image files of size

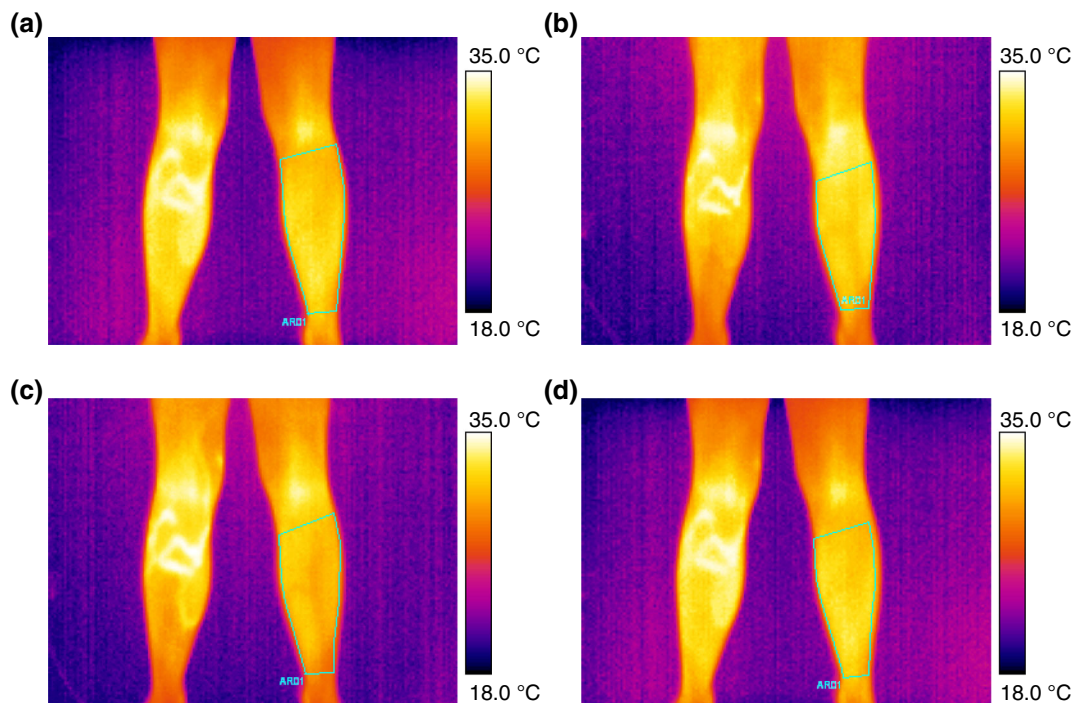


Fig. 1 Sample images of the temperature distribution for the rear surface of the *right leg*: **a** prior to the application of ultrasonic waves at a frequency of 1 MHz, **b** after applying an ultrasonic wave of a

frequency of 1 MHz, **c** before the application of ultrasonic waves at a frequency of 3 MHz, **d** after application of ultrasonic waves with a frequency of 3 MHz

320 × 240 pixels in jpg format. An appropriate scale of temperatures was selected (18–35 °C), enabling the correct interpretation of curves. The obtained material was subjected to computer analysis using theThermaCAMResearcher2.9 program. The scale of rainbow colors was used to illustrate different temperatures of curves. In order to analyze the temperature of the skin around the Achilles tendon, it was necessary to trace the contours on the curve. Examples of thermal images are shown in Fig. 1.

The collected results of individual measurements of each subject were placed in a database, then they were subjected to statistical analysis using STATISTICA10PL program, calculating the average, minimum and maximum temperature, standard deviation, and coefficient of variation.

In order to determine the significance of average temperatures, there were both parametric and non-parametric analyses of variance conducted. Since the probabilities overlap, description of the results with the use of the parametric analysis was adopted. Duncan's test, which is a continuation of the analysis of variance, in case of a significant change, was then performed. Due to the adoption of the parametric analysis of variance, there was student's *t* test applied. As statistically significant value of tests and coefficients, the level of $p < 0.05$ was taken. Statistically significant values were made in bold in tables.

Results and discussion

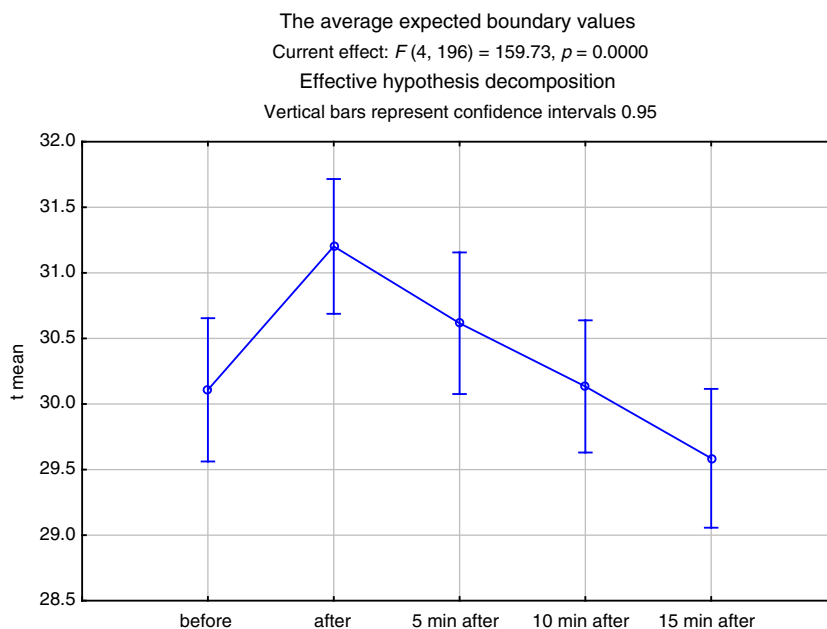
On the basis of thermal images, the descriptive statistics of the tested area of Achilles tendon before and after the treatment with ultrasound wave at a frequency of 3 MHz were made (Table 1, Fig. 2).

After applying a single treatment with ultrasound wave at a frequency of 3 MHz, there was an increase in the average temperature in the Achilles tendon observed, which continued for 10 min after the procedure. The average temperature recorded immediately after the treatment was higher than the average initial temperature by 1.09 °C, in the 5th min by 0.51 °C, whereas in the 10th minute, the difference equaled 0.02 °C. The measurement made 15 min after the procedure showed a decrease compared to the average temperature measured before the treatment by 0.52 °C.

By subjecting the results to further analysis, there was Duncan's test used, which showed a statistically significant differences. Significant temperature is relative to the average temperature before the treatment, it showed changes immediately after the treatment, and 5 min after the treatment. Statistically significant was also a change in the mean temperature before the treatment in reference to the one measured 15 min after its completion. In this case, the difference in the reduction of temperature appeared to be significant. Measuring of the difference in average

Table 1 Descriptive statistics for the rear surface of the lower leg at a frequency of 3 MHz

Treatment time	Characteristic					
	N	Mean	Minimum	Maximum	SD	Variation coefficient
Before treatment	50	30.11	25.10	33.20	1.922	6.38
After treatment	50	31.20	26.40	34.50	1.809	5.80
5 min after treatment	50	30.62	26.20	34.30	1.899	6.20
10 min after treatment	50	30.13	25.70	33.10	1.774	5.89
15 min after treatment	50	29.59	25.00	32.20	1.862	6.29

Fig. 2 Graphical presentation of the average temperature values for the back surface of upper limb treated with ultrasound wave at a frequency of 3 MHz**Table 2** Duncan's test for mean values of temperature prior to the treatment and subsequent stages of measurements at a frequency of 3 MHz (statistically significant values in bold)

Measurement phases	Frequency 3 MHz
Before treatment–after treatment	0.0000
Before treatment–5 min after treatment	0.0000
Before treatment–10 min after treatment	0.7028
Before treatment–15 min after treatment	0.0000

$p < 0.05$

temperatures before and 10 min after the procedure showed no statistical significance (Table 2).

We know that the mechanical energy of the ultrasonic wave, being absorbed in the tissues, gives rise to thermal energy. The higher the frequency of the wave, the greater the absorption, and thus the stronger its action. Analyzing the above data in reference to the heat of ultrasound, it can be concluded that an ultrasound wave with the frequency of 3 MHz allows us to obtain a significant increase in the

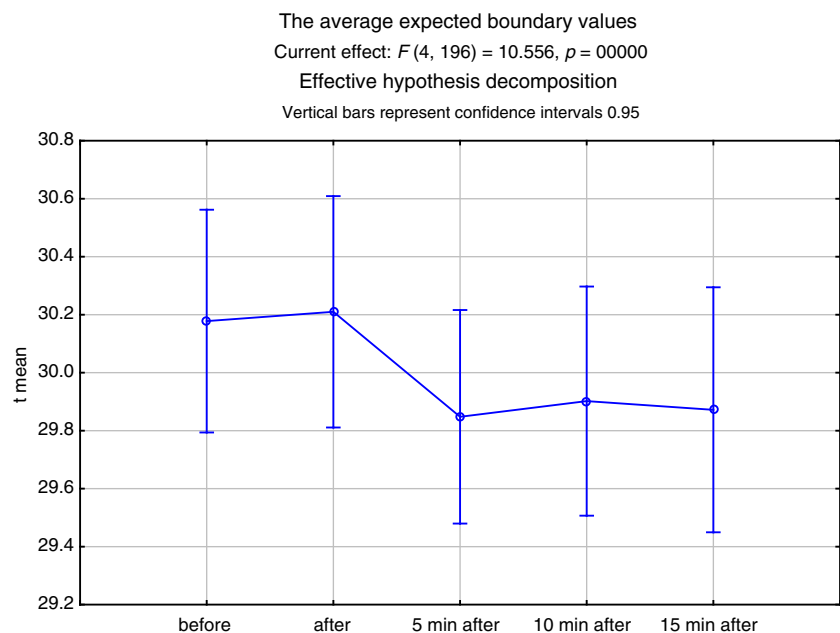
surface tissue temperatures. The results indicate, however, that this effect is short-lived, lasting for 5 min after the procedure.

Then a comparison of the average surface temperature of Achilles tendon before and after the treatment with ultrasound at a frequency of 1 MHz was made. Table 3 presents the mean values of temperature, standard deviations, and variation coefficients.

Under the influence of a single treatment with ultrasound wave at a frequency of 1 MHz immediately after the treatment, there was a slight increase in the average temperature around the measurement area in relation to the average temperature prior to the treatment. The average temperature of the skin surface of Achilles tendon increased on average by 0.3 °C compared to the average initial temperature. Subsequently, there was average temperature before the treatment compared to average temperatures in the 5th, the 10th, and the 15th min after the use of ultrasound wave with a frequency of 1 MHz. In each of these measurements, there was a decrease of temperature with reference to the starting temperature. In case of

Table 3 Descriptive statistics for the rear surface of the leg at a frequency of 1 MHz

Treatment time	Characteristics					
	N	Mean	Minimum	Maximum	SD	Variation coefficient
Before treatment	50	30.18	26.80	32.60	1.352	4.48
After treatment	50	30.21	26.80	32.50	1.404	4.65
5 min after treatment	50	29.85	26.50	32.80	1.296	4.34
10 min after treatment	50	29.90	26.30	33.00	1.391	4.65
15 min after treatment	50	29.87	25.90	33.10	1.487	4.98

Fig. 3 Graphical presentation of the average temperature values for the back surface of the leg treated with ultrasound waves at a frequency of 1 MHz

measurements 5 min after the treatment, the difference was 0.33 °C, 10 min after it equaled 0.28 °C, whereas 15 min after it was 0.31 °C. The observations showed that the surface temperature of the muscle treated with ultrasound wave at a frequency of 1 MHz 5 min after the treatment showed a declining trend, reaching a value below the temperature before the treatment (Fig. 3).

Statistical analysis performed with the use of Duncan's test showed no statistically significant differences between the temperature before the treatment and immediately after it. Statistically significant changes were observed 10 and 15 min after the treatment. Both values related to the differences associated with a decrease in temperature compared to the temperature measured before the treatment. Test values are shown in Table 4.

Ultrasound wave at the frequency of 1 MHz is absorbed less, therefore, its both thermal and mechanical effects are lower in surface tissues and larger in the deeper-lying ones. Reduction of the tissue temperature and the associated reduction of the blood volume in the vessels in the surface

Table 4 Duncan's test for mean values of temperature prior to surgery and subsequent stages of measurements at a frequency of 1 MHz (statistically significant values in bold)

Measurement phases	Frequency 1 MHz
Before treatment–after treatment	0.6773
Before treatment–5 min after treatment	0.6773
Before treatment–10 min after treatment	0.0003
Before treatment–15 min after treatment	0.0001

$p < 0.05$

of the given area result in an increase of these parameters in the deeper layers.

The next step in analysis of the results was a comparison of average temperatures after the treatment with ultrasound wave at the frequency of 3 and 1 MHz. Since there was no significant difference in the temperatures measured before the treatment in both groups, further analysis did not require action on the basis of differences in average temperatures.

Table 5 Student's *t* test for dependent samples—a comparison of the temperature of the same parameters at the frequency of 3 and 1 MHz

Variable	Test	
	T	<i>p</i>
Before 3 MHz treatment—before 1 MHz treatment	−0.2254	0.8225
After 3 MHz treatment—after 1 MHz treatment	3.3341	0.0016
5 min after 3 MHz treatment—5 min after 1 MHz treatment	2.6037	0.0121
10 min after 3 MHz treatment—10 min after 1 MHz treatment	0.7918	0.4322
15 min after 3 MHz treatment—15 min after 1 MHz treatment	−0.9306	0.3565

p < 0.05

The result of the Student's *t* test showed statistically significant difference in average temperatures measured immediately after the treatment, and 5 min after the procedure at the frequency of 3 and 1 MHz. A comparison of temperature values for both frequencies 10 and 15 min after the treatment was not statistically significant (Table 5).

Conclusions

In the study experiment, there were used mean values of parameters, adopted in ultrasound wave treatment, in reference to power, treatment duration time, and duty cycle.

Apart from the result obtained immediately after the treatment and 5 min after the operation, at the frequency of 3 MHz, the thermal effect was not observed.

In the materials about ultrasound wave, there is always the information about the heat activity of the ultrasonic wave [9, 10, 23, 24].

The outcomes indicate that an increase in surface temperature is caused only in the result of ultrasound wave with a frequency of 3 MHz. The same procedure using a lower frequency does not contribute to changes in tissue temperature in the treated area. Ultrasound wave treatment, in which the average parameter values used in physical therapy are adopted at the frequency of 3 MHz, is the thermal treatment. Studies measuring the temperature change under the influence of various physical factors were mostly carried out by means of a digital thermometer or pyrometer [7, 8, 14, 25]. With precise measurement tools, which include thermography, one should not generalize the impact of the ultrasonic wave, taking into account the thermal effect. Hospitalization, treatment at outpatient clinic or spa resort will have better therapeutic impact, if the parameters of the treatment are determined individually, depending on the individual needs of the patient, and the energy in the form of a physical factor will be delivered to tissues in a precisely planned way.

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