INVESTIGATING THE TEMPERATURE EFFECTS OF A LOW-POWER LASER ON A TISSUE-LIKE MATERIAL USING NTC-TYPE THERMISTOR SENSORS AND CALCULATING ENERGIES BY HEAT TRANSFER EQUATION

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In this study, we aimed to investigate the temperature effects of a low-power laser on a tissue-like material, namely muscle phantom. To do this, we used thermistor temperature sensors to measure the temperature of the material at various points while it was exposed to the laser. We found that the temperature of the material increased with increasing duration of exposure to the laser, however, the maximum temperature increase was 1.7 degrees Celsius for 80 seconds, which is not harmful to tissues. Next, we applied this temperature difference information to the heat transfer equation, a mathematical model that describes how heat is transferred from one body to another. By using the measured temperature difference values and known variable such as the material's specific heat capacity, we were able to calculate the amount of energy per 1 gram produced by laser light at different distances and durations. We found that the maximum energy produced was 8.4 J for 80 s or a fluence of 0.105 J/cm² per second. This information is important because it can help us understand how the laser's energy is absorbed by the tissue-like material and how it affects the material's properties and structure. It can also provide insight into the potential therapeutic effects of low-level laser therapy, a non-invasive treatment that uses lasers to stimulate healing and reduce pain and inflammation in the body, and for determining appropriate treatment doses for various diseases.

Keywords. Tissue-Like Material, Low Power Laser, Temperature Effects, NTC-Type Thermistor Temperature Sensor, Heat Transfer Equation, Specific Heat Capacity, Energy Calculation.

INTRODUCTION

Tissue-like materials are used in many fields such as biomedical research [1], testing medical devices and instruments [2], surgical training [3], biophysics [4], and medical imaging such as ultrasound [5,6], MRI [7], CT [8,9] and PET [10]. In the field of biomedical engineering, tissue-like materials are materials that mimic the mechanical properties of biological tissues and are used in various research projects. For example, The mechanical and morphological characteristics of human anatomical features must be accurately modeled for use in medical teaching and research. While some models use preserved human cadavers or animal tissue as biological substitutes for fresh human tissue, other models are constructed of artificial materials due to both practical considerations and ethical issues [11]. In the field of testing medical devices and instruments, tissue-like materials are used to simulate the effect of devices on human tissue. For instance, the radiation impact of a cell phone may be tested using a substance that resembles tissue. As a result, it is possible to get more precise information regarding how mobile phones affect human tissue [12]. In surgical training, tissue-like materials are used to help prospective surgeons learn surgical techniques. For example, a solid model will provide the learner with something tangible to work on rather than a 2D computer-generated representation since, according to one research, 42% of new doctors do not feel confident doing an unsupervised surgery. By assisting the student in visualizing the surgery and comprehending the anatomy of the patient's organ, the realistic model can boost their confidence [13]. In the field of biophysics, tissue-like materials are used to study the physical properties of biological tissues. For instance, it is necessary to control this dose and keep it as low as practically possible to prevent biological harm to the body. This worry is taken into account, and a radiation planning technique is implemented to bring the situation safe. Before exposing the human body to the radiation technique, radiation planning involves reviewing the actual operation with tissue-like materials to determine the safety and acceptable energy range [14]. Tissue-like materials are also used in the field of medical imaging to evaluate imaging methods. For instance, high-quality tissue-mimicking phantoms (TMPs) are essential for the preclinical testing of novel diagnostic and therapeutic modalities. TMPs should be manufactured with exact T1 and T2 relaxation periods in order to precisely simulate actual tissue in Magnetic Resonance guided Focused Ultrasound (MRgFUS) applications [15]. Phantoms are also used for many other purposes, such as calibrating the optical field, testing the accuracy of measurements, and evaluating the performance of optical systems. Phantoms can also be used to evaluate the quality and performance of radiological imaging systems [16, 17]. The phantom looks as the device displays, but has previously known features. In this way, the images of the device can be evaluated for accuracy and precision. Phantoms can also be used for calibration of optical systems. For example, a phantom can be used to test the accuracy of a laser scanning system [18].

Low-level laser therapy (LLLT) is a medical treatment that utilizes lasers with low levels of energy to stimulate tissues in the body. It is sometimes referred to as "cold laser therapy" due to the fact that the lasers

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do not generate heat when applied to the skin. LLLT devices are often used to treat a variety of conditions, including muscle and joint pain, inflammation, and wounds. The theory behind LLLT is that the low-energy lasers stimulate the cells in the body to produce energy, which can reduce pain and inflammation and promote healing. There are several factors that can impact the effectiveness of LLLT, such as the wavelength of the laser, the power of the laser, the exposure time, the intensity of the laser, the output mode, the depth of penetration, the area being treated, and the settings on the control panel. While some research supports the use of LLLT for certain conditions, further studies are needed to fully understand its effectiveness and the optimal treatment protocols. It is important to note that LLLT should not be used as a replacement for proven medical treatments, and it is always important to consult with a qualified healthcare professional before starting any new treatment. LLLT is used to treat a variety of ailments. For example, LLLT can help reduce pain. In particular, LLLT may be effective in chronic pain syndromes [19]. Again, LLLT is known to help accelerate wound healing [20]. Another example, LLLT can help reduce pain and speed up the healing process in tendonitis [21]. And finally, LLLT can help reduce pain and improve mobility in osteoarthritis [22]. Low-level laser therapy (LLLT) devices utilize low-energy lasers to apply laser beams to tissues. These lasers can operate at various frequencies and have different longitudinal modes (LMod) such as TEM00, TEM01, and TEM10, which refer to different wavelengths. The power of the laser beams, typically measured in milliwatts (mW), can be controlled by the LLLT device. LLLT devices can apply laser beams to tissues in a variety of ways, including at a single point or multiple points, with different exposure times for example ranging from 5 minutes to 30 minutes, and at different intensities and output modes, such as continuously or in waves. The depth and area of tissue that the laser beams are applied to can also vary, and LLLT devices usually have a control panel to adjust these parameters and control the device [23, 24].

Temperature measurement is an important measurement in many different fields. For example, in the health field, temperature measurement helps to measure body temperature and helps to detect whether there are health problems in cases of low or high body temperature. Normal human body temperature can vary between 36.5-37.5 degrees Celsius according to various body parts [25]. However, each individual's body temperature may differ slightly, and sometimes there may be a difference between morning and night temperature. In addition, body temperature can vary according to the age, gender and level of physical activity of the person. For example, the body temperature of children is usually slightly higher, and the body temperature of the elderly is usually slightly lower [26]. A body temperature of 37 degrees Celsius or above is defined as a high temperature or fever. In this case, it is recommended to consult a doctor.

Also, if the body temperature is 35 degrees Celsius and below, it is defined as a low temperature and it is again recommended to consult a doctor in this case.

The heat transfer equation in tissues has been investigated [27-30]. The study of heat transfer in tissues is important for various medical applications. For example, understanding the heat transfer in tissues during the design of medical devices can help evaluate the effect and safety of the device to the tissues. It can also help to understand the heat transfer in tissues of devices such as therapeutic heating and cooling pads, so that the efficacy and safety of the devices can be better understood. Treatments such as cryotherapy and radiofrequency ablation are also applied by considering the factors affecting heat transfer in tissues, and therefore understanding the heat transfer in tissues is important for the effectiveness and safety of these treatments [31,32]. Heat transfer in tissues occurs by various mechanisms, including conduction, convection, and radiation. The heat transfer equation can be used to predict the rate at which heat is transferred through tissues based on the properties of tissues (such as their thermal conductivity and specific heat capacity), the heat transfer coefficient, and the temperatures of the tissues . To accurately model heat transfer in tissues, it is important to consider the complex and inhomogeneous nature of tissues and the presence of blood vessels, which, due to their high thermal conductivity, can significantly affect heat transfer and convective heat transfer caused by blood flow. In addition to the heat transfer equation, other mathematical models and techniques, such as finite element analysis, are often used to study heat transfer in tissues and to predict the temperature distribution and thermal response of tissues to exposure to heat or cold [33]. Why is it important to investigate heat distribution in tissues? Because the distribution of tissue heat helps to understand and evaluate the heat balance in the body. The human body uses a number of mechanisms to control body temperature, and the operation of these mechanisms also affects the distribution of tissue heat. For example, when the body temperature is high, the body tries to expel the heat through water and perspiration. Therefore, the distribution of tissue heat is important for understanding the heat balance in the body. In addition, the distribution of tissue heat is also important in assessing the state of health in the body. For example, an abnormal heat distribution in an area may indicate the possibility of a health problem in that area. Therefore, investigating the distribution of tissue heat helps to understand and evaluate health status in the body [34].

In this study, we tried to understand how low-power laser exposure dissipates temperature on a tissue-like material. To do this, we used NTC-type thermistor temperature sensors to measure the temperature of the material at various points during laser exposure. This temperature difference was then applied to the heat transfer equation, a mathematical model that describes how heat is transferred from one body to another. Using the measured temperature differences and known variables such as the specific heat capacity of the material, we calculated the amount of energy per one gram produced by the laser at different distances and times. This information can help to understand how laser energy is absorbed by the tissue-like material and affects the properties and structure of the material. It can also provide insight into the potential therapeutic effects of low-level laser therapy, a non-invasive treatment that uses lasers to promote healing and reduce pain and inflammation throughout the body.

METHODOLOGY

In this study, the muscle phantom, the VA-I-400-635 model 635 nm red-colored solid-state diode laser, UME MEDMET temperature measurement system and NTC-type thermistor temperature sensors were used. Later using the specific heat information of the muscle phantom and the detected temperature values, the energy distributions were calculated using heat transfer equations. All experiments were performed under controlled laboratory ambient conditions.

PREPARATION OF MUSCLE PHANTOM

In this study, a muscle phantom was used that was identical to one previously published by Gutierrez et al [35]. The phantom was created by mixing together agar, aluminum oxide, distilled water and heating the mixture until it reached a 80 °C temperature. After dropping the temperature of the solution to 60 °C, 10 mL of glycerin was added to the solution and then the solution was poured into a special designed measurement mold and allowed to freeze. This process was used to create a model that could be used to study the properties of muscle tissue.

LASER SOURCE

The VA-I-400-635 model of the Optotronics brand, which is a red-colored solid-state diode laser with a 635 nm wavelength, was used as the optical source for the measurements. The laser utilized in the study can be seen in Figure 1.

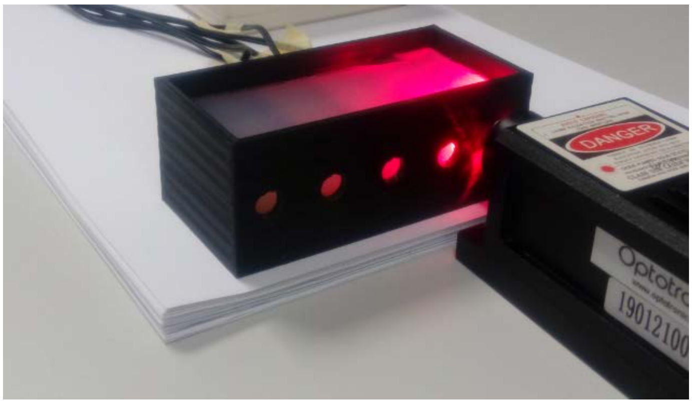

Fig. 1. A picture of the laser used in the study.

TEMPERATURE MEASUREMENT SYSTEMS AND NTC-TYPE THERMISTOR TEMPERATURE SENSORS

The temperature measurement system used in the study was the UME MEDMET system developed by our laboratory. It employed NTC-type thermistor temperature sensors and had five connectable 10 kΩ sensors with a sensitivity of 0.5%. A picture of measurement system and phantom container can be seen in Figure 2.

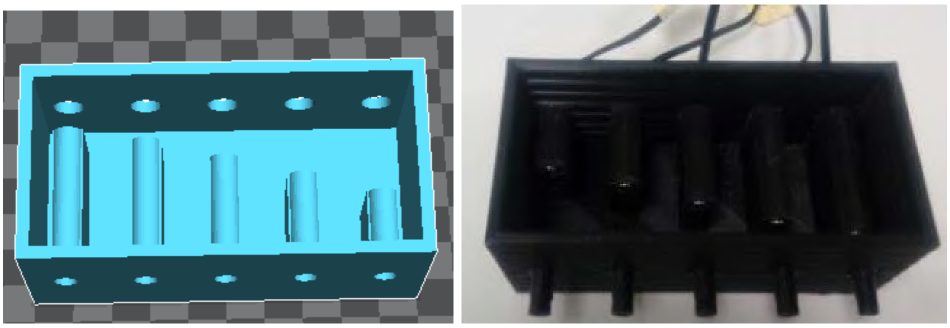

Fig. 2. Temperature Measurement Systems and NTC-Type Thermistor Temperature Sensors.

In the experiment, measurements were taken by applying the laser from various points, as shown in Figure 3. The Temperature Measurement Device (UME MEDMET) used in this experiment was developed in-house and allows for the connection of five 10 kΩ NTC type thermistor temperature sensors. The device's outer box was designed using the Solidworks program and printed on the 3D printer (Zaxe X1+) in the laboratory. It receives power directly from the connected computer through a USB connection and has a TFT touch screen for inputting commands and reading data. The device's software was also developed in the laboratory, and data can be transferred to an MS Excel file if desired.

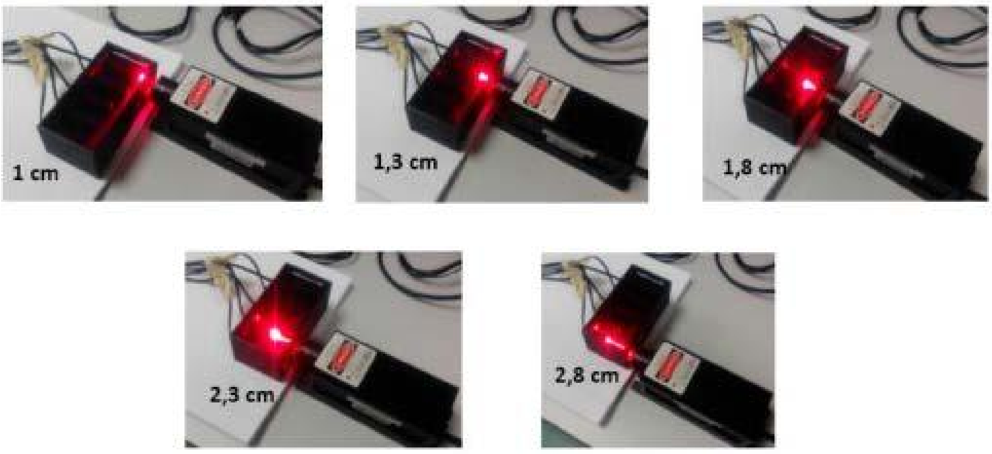

Fig. 3. The pictures of measurement points in the phantom container.

HEAT TRANSFER EQUATION AND PHANTOM'S SPECIFIC HEAT INFORMATION

The heat transfer equation is a mathematical expression that describes the rate at which heat is transferred from one place to another as a function of various physical properties and conditions. It is typically used in various engineering and scientific applications to estimate the rate of heat transfer between two bodies or between an object and its surroundings. The quantitative relationship between heat transfer and temperature change contains all three factors [36];

$$Q = mc\Delta T \tag{1}$$

where "Q" is the symbol for heat transfer, "m" is the mass of the substance, and "ΔT" is the change in temperature. The symbol c stands for specific heat and depends on the material and phase. The specific heat is the amount of heat necessary to change the temperature of 1.00 kg of mass by 1.00 °C. The specific heat is a property of the substance; its SI unit is or J/(kg·K) or J/(kg·°C). Recall that the temperature change (ΔT) is the same in units of kelvin and degree Celsius. If heat transfer is measured in kilocalories, then the unit of specific heat, kcal/(kg·°C). By using the heat transfer equation, we can predict how much heat will be transferred between two bodies or regions under given conditions, which can be useful for designing and optimizing heat transfer systems and devices, such as heat exchangers, boilers, and refrigerators. In the energy calculation of the muscle phantom, the specific heat value is taken as an average of 3650 J/(kg·°C) as literature information [37].

RESULTS AND DISCUSSION

The temperature and heat distribution graphs caused by the low-power laser applied to the muscle phantom at different times are given below. Figure 4 shows the temperature distribution created by the low-power laser in the experimental setup for 20, 40, 60 and 80 s times.

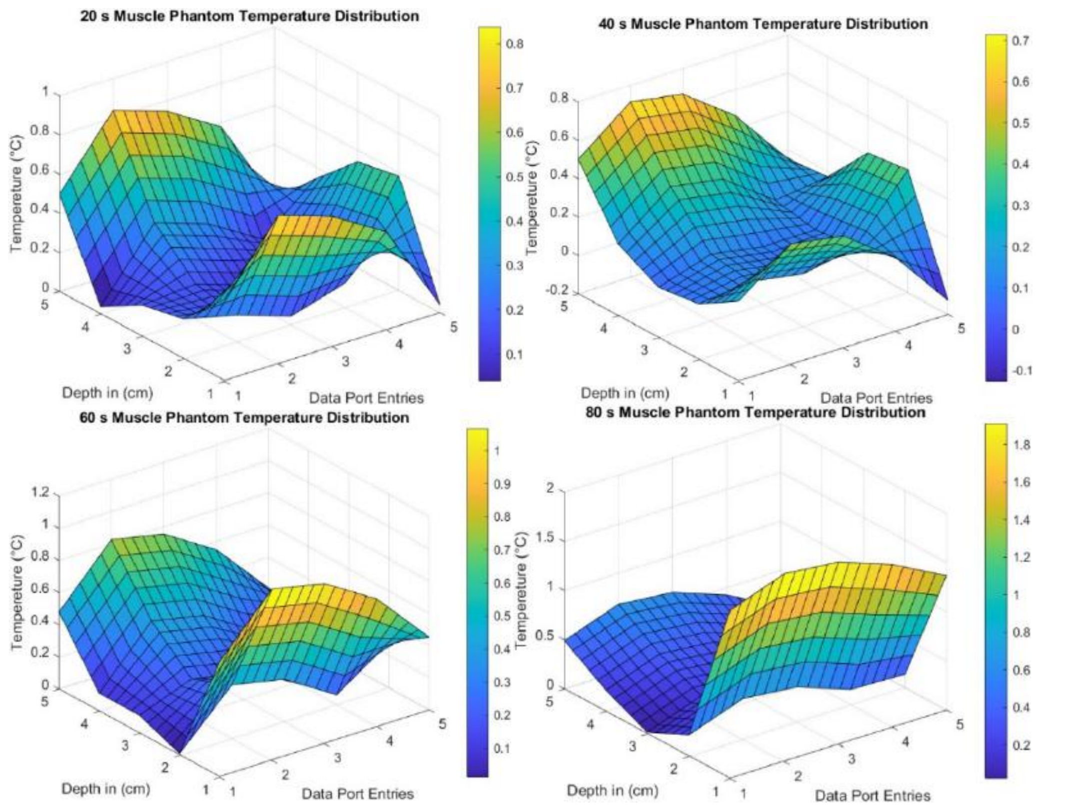

Fig. 4. The temperature distribution created by the low-power laser in the experimental setup for 20, 40, 60 and 80 s durations.

Figure 5 shows the energy distributions calculated using the measured temperature differences and the specific heat capacity of the muscle phantom for the 20, 40, 60 and 80 s times.

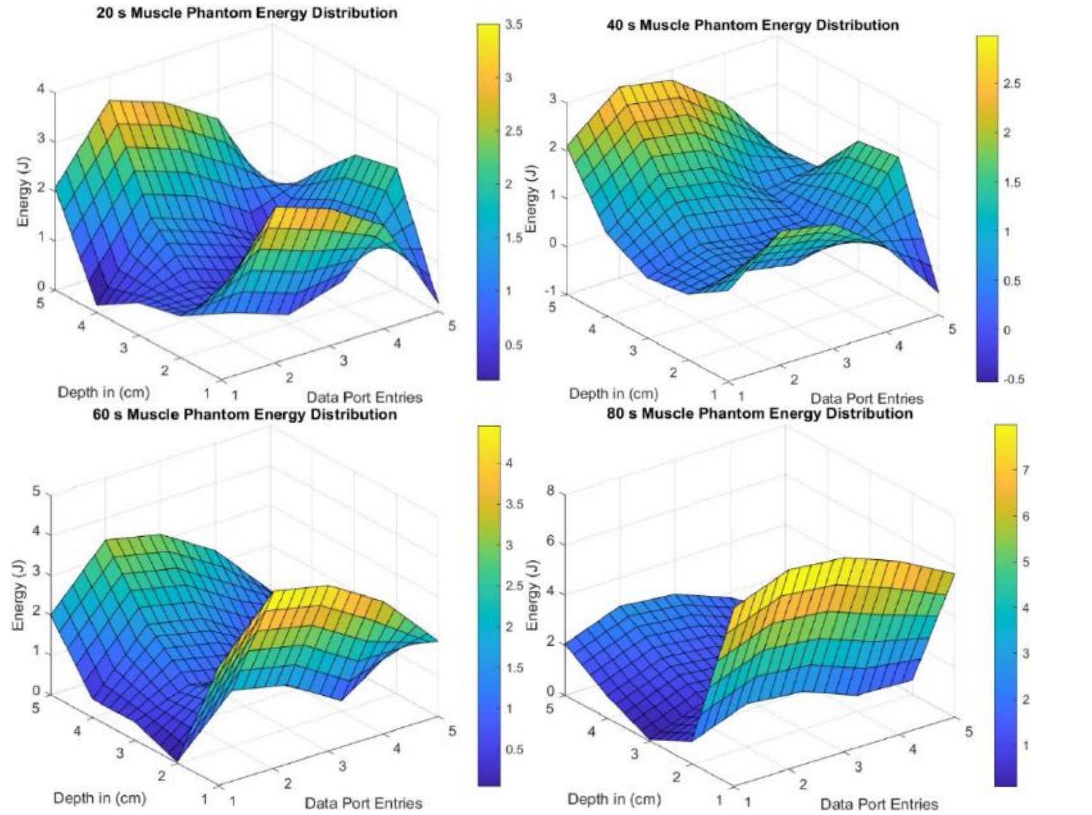

Fig. 5. The energy distribution created by the low-power laser in the experimental setup for 20, 40, 60 and 80 s durations.

DISCUSSION

In this study, laser-induced temperature measurement was investigated using NTC-type thermistor temperature sensors and UME-MEDMET temperature measurement system inside the muscle phantom. All the experiments done for temperature measurements were carried out under laboratory ambient conditions (Temperature was 23.0 °C ± 3 °C, and relative humidity was 50 rh% ± 5 rh%). It is seen that the temperature of the material increases with the increase of the exposure time of the material to the laser. The temperature rises over time can be seen much more clearly from the graphs. The temperature increases caused by the laser in the muscle phantom are a maximum of 1.7 Celsius degrees for 80 s. The maximum temperature detected was found as 23.4 °C and the average temperatures measured when the laser was applied were found as 21.7 ± 0.5 °C. When we add the maximum temperature difference and temperature uncertainty (0.94 °C) coming from the NTC type thermistor temperature sensor [38] to the average temperatures found for the muscle phantom, the temperature value to be formed will be 24.8 °C at the most. We can also adapt this assessment to human body temperature. Because the human body temperature is 37 +/- 0.5 °C [25], the maximum temperature increase found will lead to a maximum increase of 3.2 °C in body temperature, taking into account the temperature uncertainty of the measurements and the uncertainty of the NTC temperature sensor. This can raise body temperature to 40.2 ± 0.5 °C. These temperatures are harmless. Because temperatures exceeding 45 degrees cause damage to the tissues [39]. Therefore, these temperatures will only produce photochemical effects, also known as biostimulation. In other words, the laser used will not create irreversible effects. The temperatures and temperature differences found are mostly of the type that trigger photochemical processes rather than photothermal effects. At the same time, it is seen that the 400 mW laser can be used safely on people up to 80 seconds and a minimum approach distance of 25 mm.

We can also say the following about the energy distributions calculated over the detected temperatures. The heat increases caused by the laser in the muscle phantom were calculated as 8.4 J maximum for 80 seconds. In laser treatment for various diseases and symptoms, there are specific guidelines for the number of treatments, the intervals between treatments, and the method and dosage (measured in fluence, or J/cm^2) that should be followed, as outlined in a reference source [40]. The calculated energy of 8.4 J for 80 s corresponds to 0.105 J/cm^2 per second. For this reason, appropriate treatment planning can be made for the energies defined for the treatment of various diseases. For example, the following doses (fluences) per cm^2 are applied in the treatment of the following diseases and symptoms; Carpal-tunnel (8 J/cm^2), Supraspinatus (8 J/cm^2), Patellar tendon (8 J/cm^2), Achilles tendon (8 J/cm^2), Acne Vulgaris (5 J /cm²), Allergic rhinitis (5 J/cm²), Arthritis (5 J/cm²), Wound healing (edge of wound) (5 J/cm²), Scars and pregnancy stretch marks (5 J/cm²), Muscle knots and pain (5 J/cm²) and Tendinitis (5 J/cm²).

CONCLUSION

In conclusion, tissue-like materials are widely used in various fields, including biomedical research, testing medical devices and instruments, surgical training, biophysics, and medical imaging. These materials are used to mimic the mechanical properties of biological tissues and are valuable for studying the physical properties of tissues, evaluating imaging methods, calibrating optical systems, and more. Low-level laser therapy (LLLT) is a medical treatment that uses low-energy lasers to stimulate tissues in the body and is used to treat a range of conditions, including muscle and joint pain, inflammation, and wounds. While there is some evidence to support the use of LLLT for certain conditions, more research is needed to fully understand its effectiveness and the optimal treatment protocols.

Based on the results of this study, it can be concluded that the use of the 400 mW laser on people for up to 80 seconds with a minimum distance of 25 mm is safe and will not produce harmful, irreversible effects. The laser caused an increase in temperature of the muscle phantom, with a maximum increase of 1.7 °C for 80 seconds. When considering the uncertainty in the temperature measurement and the sensor used, this could potentially lead to an increase of 3.2 °C in human body temperature, bringing it to a safe level of 40.2 ± 0.5 °C. The temperatures and temperature differences produced by the laser are mostly of the type that trigger photochemical processes rather than photothermal effects. As for the produced energy, the heat increase caused by a laser in a muscle phantom was calculated to be 8.4 J maximum over 80 seconds. This corresponds to a fluence (energy per unit area) of 0.105 J/cm^2 per 1 s. There are specific guidelines for the number and timing of laser treatments for various diseases and symptoms, and the appropriate treatment can be planned based on the energy levels defined for each condition. Future studies could examine the use of lasers with different powers and different types of phantoms to further understand the effects of laser-induced temperature measurement.

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