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# Investigation of temperature effects of a low-level laser source within the muscle phantom

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**ABSTRACT**

In this study, temperature effects of a low-level laser source were investigated in a muscle phantom within 20, 40, 60, and 80 seconds time intervals. A temperature meter device having a 5-channel and 10 kΩ negative temperature coefficient (NTC) type thermistor sensors were developed in TÜBİTAK UME Medical Metrology Laboratory for these special temperature measurements. The muscle phantom poured into a phantom container that was specially designed for 5-channel sensor placement and printed in a 3D printer. It has also been acoustically confirmed that the phantom has muscle phantom characteristics. As a result of this study, it is concluded that the laser source used is safe and suitable at therapy usage within the specified times in terms of the detected temperatures.



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## 1. INTRODUCTION

Low-level laser therapy (LLLT) is a photobiostimulation therapy that has been used in physiotherapy practice for the treatment of a wide range of condition and it is preferred because it is effective, noninvasive, safe, and cost-efficient [1]-[4]. LLLT regulates biological processes, including cell growth, apoptosis, angiogenesis, cell proliferation, and differentiation. It also aids to develop the collagen synthesis and the blood supply. Increased production of adenosine triphosphate (ATP), ribonucleic acid (RNA), and deoxyribonucleic acid (DNA) (thus improving nutrition, regeneration and cellular oxygenation) and increased microcirculation are the most significant biostimulatory effects of LLLT. This therapy advances tissue regeneration/restoration/repair activity, reducing inflammation, improving wound healing and neural function processes, reducing edema, and relieving acute or chronic pain (analgesic effect) [5]-[10]. Because it is effective in reducing pain and improving muscle performance, it is highly preferred in the treatment of musculoskeletal disorders that decrease the quality of life due to pain and limitation of movement [5], [11]. Use of applications that increase the temperature of muscle tissue in the physiotherapy clinic generates many therapeutic effects such as vasodilation (dilation of blood vessels), promoting blood flow, muscle cell activation that can encourage relaxation, tissue renewal that helps promote DNA synthesis and therefore cell proliferation [12]-[14]. But rising tissue temperature above 45 °C causes irreversible damage [15]. Therefore, care should be taken not to increase the temperature to this value in the treatments applied.

Tissue-mimicking phantoms are widely used in scientific research fields such as ultrasonics, photoacoustics and biophotonics as test models [16]-[18]. Furthermore, it is also benefited from tissue equivalent phantoms in evaluating any new diagnostic or therapeutic modality, in the calibration and standardization of the new technique before starting clinical practice and in simulating the optical properties of biological tissues [19], [20].

Muscles in the human body have a peerless structure and a certain function. There are over six hundered muscles that make up about fourty percent of human body weight. Each muscle is made up of thousands or tens of thousands of small muscle fibers. Each muscle fiber is controlled by a nerve, which allows the muscle to contract. There are three kinds of muscles in the human body. These are heart muscle, smooth muscle, and skeletal muscle. Only skeletal muscles are voluntary, so you can consciously control them. Smooth and heart muscles act involuntarily. Skeletal muscle moves bones and other structures. Skeletal muscles contract and relax, stick on the bones and act in response to voluntary messages from the nervous system. Smooth muscle tissue, which forms organs such as stomach and bladder, allows internal organs to work. The heart muscle contracts the heart to pump blood. We always need the muscular system when moving, standing, talking, breathing, chewing and digesting a food, pumping blood in the heart, seeing an object, and regulating our body temperature. Therefore, the muscular system is a complex muscle network that is vital for the human body. The muscular system has eleven main functions. These are listed as mobility, stability, posture, circulation, respiration, digestion, urination, birth, vision, organ protection, and temperature adjustment.

Although muscles have many functions in the human body, including temperature regulation, temperature increases above 45 °C can cause irreversible damage to the tissue. Examining the temperature changes and interactions generated by a low-level laser source on a muscle phantom is thus a significant study issue. Therefore, in this study, temperature effects induced by a low-level laser therapy source, on muscle phantom were studied at different depths of muscle phantom with the help of the phantom container designed and temperature measurement device developed specially in our laboratory having five NTC type thermistor temperature sensors. To the best of our knowledge, such a temperature measurement study was carried out for the first time on muscle phantom. Therefore, the study brings extremely an innovative method to the literature.

## 2. RESEARCH METHOD

### 2.1. Tissue-mimicking material (phantom), phantom container and laser source

Tissue-mimicking material (TMM) is generally used as a test object in biomedical research because of its capability to model biological soft tissues. In this study, we utilized a muscle phantom similar to the one described by Gutierrez *et al.* [21]. It was also acoustically confirmed that the phantom had a muscle phantom characteristic. The speed of sound found was 1550.9 ± 48.4 m/s (Ref: 1547 m/s [22]). We prepared the phantom as follows. 2.3 g of agar and 10.7 g of aluminum oxide are added to 125 mL of distilled water in a container. The magnetic stirrer is gradually increased to 400 revolutions per minute and mixed with the help of fish. The temperature of the solution is heated until it rises to 80 °C. When it reaches 80 °C, the heat is cut and the solution is expected to decrease to 60 °C. At 60 °C, 10 mL of glycerin is added to the solution with a syringe. Meanwhile, the solution is continued to be mixed with the fish. When the temperature of the solution reaches 40° C, the solution is poured into the phantom mold and left to freeze. A special phantom container was designed in dimensions 50 mm in width, 100 mm in length and 40 mm in height as shown in Figure 1. There were designed five pieces measurement points passing through at the middle of the depth point. NTC type thermistor temperature sensors were put at these measuring points. The distance between the temperature sensor and the point where the laser was applied were 7 mm, 10 mm, 15 mm, 20 mm and 25 mm respectively. As an optical source, Optotronics branded VA-I-400-635 model 635 nm wavelength red colored solid-state diode laser was employed for the measurements.

### 2.2. Temperature measurement device and software

The outer box of the temperature measurement device was designed in the solidworks program and printed physically on Zaxe X1 + 3D printer. There are five connectable 10 kΩ NTC type thermistor temperature sensors in the temperature measurement device. The temperature measurement device is connected to the computer and provides its energy via universal serial bus (USB). Data can be read and commands can be entered on the thin film transistor (TFT) touch screen on the temperature measurement device. The software of the temperature measurement device was developed in the TÜBİTAK UME Medical Metrology laboratory and the data can be transferred to MS Excel as raw data from this software interface. Data can also be read instantly directly from the TFT Display. The temperature measurement device, software and experiment setup can be seen in Figure 2.

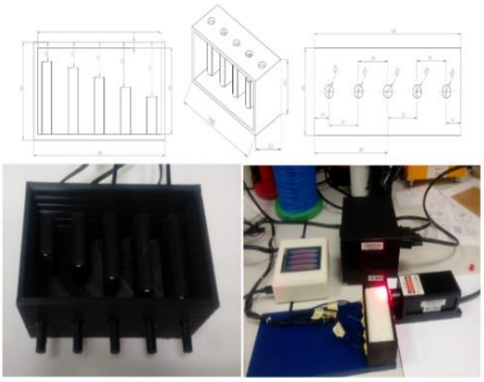

Figure 1. A special phantom container designed for the experiment

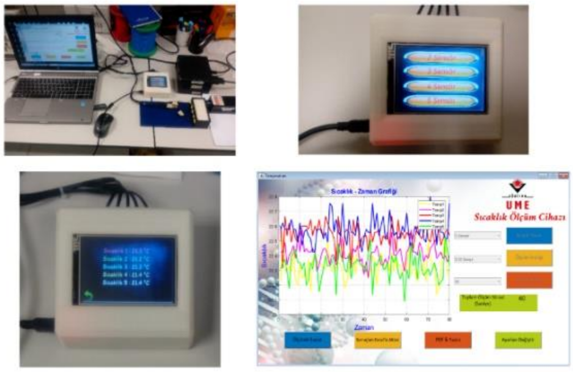

Figure 2. Temperature measurement device, software, and experiment setup

## 3. RESULTS AND DISCUSSION

### 3.1. Photothermic measurements

Firstly, the current ambient temperatures within the phantom were recorded before applying the laser. Later, the laser was applied from suitable predetermined distances to the phantom container for 20, 40, 60 and 80 seconds separately. Temperatures were recorded by thermistor type temperature sensors for each period (20, 40, 60 and 80 s). Later, the differences between the maximum temperatures seen while the laser was working and the maximum ambient temperatures detected while the laser was not working were determined for each different distance. Figure 3 shows the average temperatures determined for different distances and the different laser application durations, while Figure 4 shows the maximum temperature differences determined for different distances and the different laser application times. As seen in Figure 3, the average temperature increases as the laser application time increases. However, this increase is a thermally tolerable temperature increase for the periods studied (Max. 2.4 °C for 80 s).

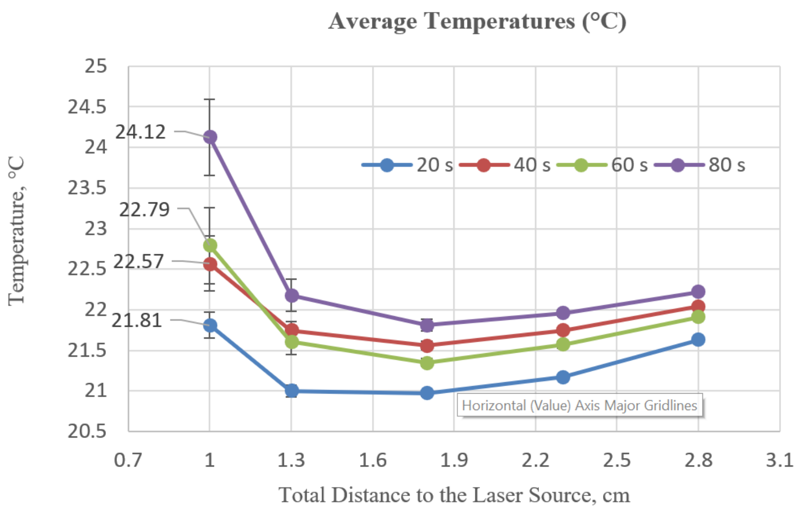


Figure 3. The detected average temparatures with respect to ambient temperatures

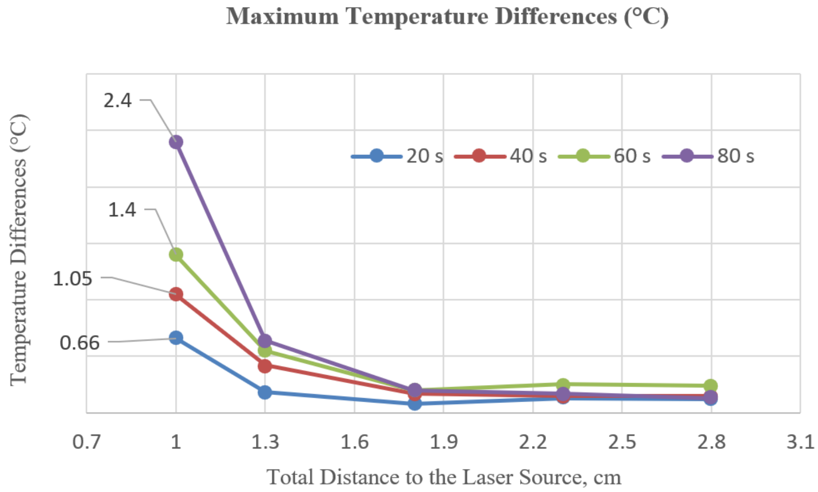


Figure 4. The maximum temeparture differences with respect to ambient temperatures

## 4. CONCLUSION

This study investigated how much a temperature effect a low-level laser source used for therapeutic purposes creates on a muscle phantom. To the best of our knowledge, the study is highly innovative as this is the first time such a temperature measurement study has been carried out on acoustically verified muscle phantom. In addition, the development of a new phantom container and a new temperature measuring device for temperature measurements on phantoms is an important innovation. Consequently, it was concluded that the temperature increases caused by the low-level laser beam applied for 20, 40, 60 and 80 s on the muscle tissue-like material are safe and appropriate in terms of thermal treatment. This study once again showed that phantom experiments can be utilized as a tool for safety testing and therapy suitability of light-based devices. In the future, this study can be expanded towards the different tissue-mimicking phantoms and also improved with more sensitive temperature sensors.

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