The Stretching Window Part Two: Rate of Thermal Decay in Deep Muscle Following 1-MHz Ultrasound

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ABSTRACT: Thermal ultrasound can be effective in increasing extensibility of collagen, thus aiding joint mobilization and stretching. In 1995, we reported on the rate of temperature decay following 3-MHz ultrasound in subcutaneous tissues. We repeated that study at 1-MHz frequency to see if the stretching window is different for deep muscle. Twenty subjects had two 23-gauge thermistors inserted 2.5 cm and 5 cm deep into their triceps surae muscle. We administered 1-MHz continuous ultrasound at 1.5 W/cm^2 until the tissue temperature increased 4°C (vigorous heating). Immediately following the treatment, we recorded the rate at which the temperature dropped at 30-second intervals. We ran a stepwise nonlinear regression analysis to predict temperature decay as a function of time following ultrasound treatment. There was a significant nonlinear relationship between time and temperature decay. At 2.5 cm, the average time for the temperature to drop each degree was: 1°C = 2:34; 2°C = 6:35; 3°C = 12:10; and 4°C = 21:14. At 5 cm, the average time for the temperature to drop each degree was: 1°C = 2:31; 2°C = 6:50; 3°C = 14:32; and 4°C = 27:49. Based upon prior research, thermal decay of 1-MHz ultrasound was slower than 3 MHz, and the deeper tissue cooled at a slower rate than superficial tissue following 1-MHz ultrasound. The data illustrated that the stretching window was open longer for deep-seated structures than for superficial ones.

Many clinicians recommend ultrasound for pain relief,[17,22] wound healing,[8–10] increasing local blood flow,[1,2] increasing tendon extensibility,[3,11,15] and treating other soft tissue injuries.[4] When attempting to increase range of motion, clinicians often heat the tissue with ultrasound in order to increase the compliance of the soft tissues involved. Vigorously heating the tissue will affect the viscoelastic properties of collagen before initiating manual therapy. Studies indicate that simultaneously heating and stretching provides the best results for permanent elongation and that the optimal time to stretch the tissue is at the peak of heating.[11,15] Heating to this level also effectively enables the tissue to avoid damage from the applied load.[19,20] Ultrasound is the ideal method to achieve this higher temperature because it heats the deeper tissues without heating or burning the superficial structures.[14]

During the past two decades, the application of therapeutic ultrasound has increased dramatically. Even though the use of ultrasound is on the rise, there are still misconceptions regarding ultrasound therapy. Perhaps two of the most crucial misconceptions about ultrasound use center around how long it takes to reach an optimal heating zone during ultrasound application and how long after a treatment the tissue retains its heat.

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In 1995, we determined that it took 3 to 4 minutes to reach a therapeutic level of heating with 3-MHz ultrasound[6] and 10 minutes to heat tissues using 1-MHz ultrasound.[7] In another 1995 study, we reported rate of temperature decay following 3-MHz ultrasound and labeled this time period the "stretching window."[7] We defined the "stretching window" as the time during which the tissue temperature is ideal to apply stretching and joint mobilization procedures to efficiently increase collagen extensibility. We hypothesized that the stretching window might be different following 1-MHz ultrasound, because this frequency focuses on deeper tissue than the 3-MHz frequency. The deeper tissue should retain heat longer since the overlying structures insulate and serve as a barrier to escaping heat. If this were the case, clinicians would then have more time following ultrasound therapy to perform manual therapy on athletes with deep-seated injuries. Therefore, we studied the rate of temperature decay following 1-MHz ultrasound treatments to determine the "stretching window" for this ultrasound frequency.

METHODS

Eleven males and 9 females (20 ± 2.1 years) volunteered to participate in the investigation. Each participant signed a consent form after being informed about the possible risks of participation in such a project. We paid each subject a $20 honorarium for participation. Approval for the study was granted by the University Human Subject's Institutional Review Board.

We used the Omnisound 3000 (Physio Technology Inc, Topeka, KS) ultrasound unit, which operated at a frequency of 1.0 MHz ± 10%. The transducer head contained a lead zirconate titanate crystal. The beam nonuniformity ratio of the crystal was 1.8:1, which ensured superior beam uniformity for fast, effective heating with no hot spots. The transducer head was 5 cm in diameter and the effective radiating area was 4.5 cm^2, which indicates that nearly all of the surface was transmitting the beam. The ultrasound unit was recently calibrated.

To measure temperature changes in the muscle, we used 23-gauge thermistors (Phystek MT-23/5; Physitemp Instruments, Clifton, NJ) coupled to a monitor (BAT-10; Physitemp Instruments) that gave a digital readout of temperature in degrees centigrade. According to the manufacturer, the accuracy of temperature recordings of the probe is within 0.1°C and the monitor is also accurate to within 0.1°C. Our coupling medium was Ultra Phonic ultrasound transmission gel (Pharmaceutical Innovations, Newark, NJ) at room temperature (25°C).

The treatment site was the gastrocnemius and soleus muscles of the left leg. This area was two times the size of the effective radiating area of the transducer head and within the recommended treatment size parameters. To ensure that the treatment size was equal for all subjects, we applied a 9- × 5-cm^2 template to the target area. For this study, we measured the temperature change at both 2.5 cm and 5 cm deep, because this is the heating range of 1-MHz ultrasound and the depth of many deep-seated joints.[13]

Each subject assumed a prone position. We then measured and determined the area of greatest girth on the triceps surae muscle to use as a landmark (Fig 1). We shaved this area, cleansed it with a pofidine-iodine (Betadine) scrub, and then swabbed it with 70% isopropyl alcohol. Two 0.5-cc injections of 1% lidocaine (Xylocaine) were given subcutaneously to anesthetize the area. The lidocaine did not contain epinephrine, which might inhibit normal vascular response and obscure the results. We inserted one thermistor into each injection site on the medial aspect of the muscle belly, so that they were 2.5 cm and 5 cm beneath the skin. We connected the thermistors to the monitor and measured the temperature until it stabilized (reached its lowest point with no fluctuations for 3 minutes). We recorded this number as the baseline.

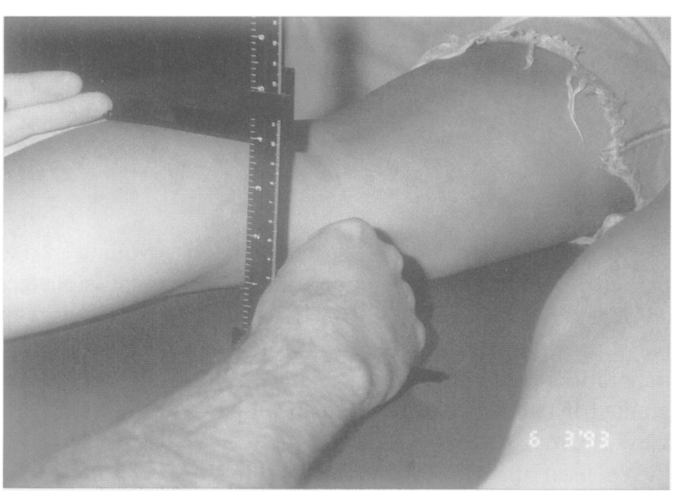

Fig 1. The examiner places a caliper on the skin and marks the two depths for the thermistor insertion (2.5 cm and 5 cm).

The goal of the treatment was to raise the temperature to a vigorous heating range and then to measure the rate of temperature decay. To accomplish this, we administered ultrasound at an average intensity of 1.5 W/cm^2 while moving the soundhead back and forth in the template at a speed of approximately 4 cm/s. We monitored the temperature rise during the treatment and recorded when the temperature had increased 4°C in the more superficial probe. After the treatment was completed, we recorded the rate of temperature decay to the nearest 0.1°C every 30 seconds. We recorded the temperature to the pretreatment baseline and continued to record the temperature until it stabilized. We removed the thermistor and placed it in a sterile solution of Cidex (Johnson & Johnson, Arlington, TX) after each subject had completed the temperature decay. We cleaned the area with 70% isopropyl alcohol and excused the subject.

Statistical Analysis

Peak temperature of each subject was normalized, or averaged, to the same point so that each temperature decay could be analyzed. Means and standard deviation from the temperature decay, measured every 30 seconds, was computed. We performed a stepwise nonlinear multiple regression on the means to predict temperature decay as a function of time.

RESULTS

At a depth of 2.5 cm, the mean baseline temperature was 34.7° ± 1.1°C. Following the ultrasound treatment, it increased to 38.7° ± 1.6°C, an average of 4.0° ± 1.1°C above the original baseline. Upon reaching the peak temperature height, the tissue took an average of 21.4 ± 4.8 minutes to return to the baseline (Fig 2).

At the 5-cm depth, the mean baseline temperature was 36.1° ± 0.5°C. Following the ultrasound treatment, the tissue tem-

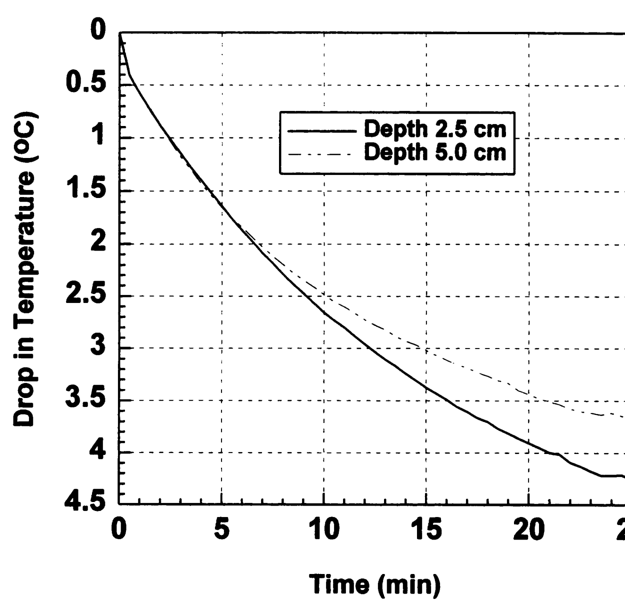

Fig 2. The rate of temperature decay at two depths following 1-MHz ultrasound.

perature increased to 39.6° ± 1.0°C, an average increase of 3.5° ± 0.8°C. Once peak temperature was achieved, 21.2 ± 4.6 minutes were needed for the tissue to return back to its original baseline temperature (Fig 2).

At the 2.5-cm depth, there was a significant relationship between temperature decay and time (r^2 = .999, SE = .038), described by the following prediction equation:

$$TD = -0.33362(t) + 0.0102(t^2) - 0.000136589(t^3) - 0.20819,$$

where *TD* is temperature decay and *t* is time.

At 2.5 cm, the temperature dropped rapidly (2°C in 6 minutes, 35 seconds) then slowed considerably as it neared the baseline (0.5°C in the last 5 minutes). The time for the temperature to drop each degree as expressed in minutes and seconds was: 1°C = 2:34; 2°C = 6:35; 3°C = 12:10; 4°C = 21:14 (baseline).

At the 5 cm depth, there was also a significant relationship between temperature decay and time (r^2 = .997, SE = .046). The prediction equation obtained at this depth was:

$$TD = -0.34396(t) + 0.01383(t^2) - 0.000228247(t^3) - 0.22137,$$

TD = temperature decay and *t* = time.

At 5 cm, the temperature also dropped quickly (2°C in 6 minutes, 50 seconds), then slowed as the temperature reached baseline. The time needed for the temperature to drop each degree as expressed in minutes and seconds was: 1°C = 2:31; 2°C = 6:50; 3°C = 14:32; 4°C = 27:49 (beyond baseline).

There was very little difference in the rate of temperature decay for the first 2°C (Fig 2). Then, as time progressed, the deeper tissues (5 cm) cooled more slowly than the more superficial ones (2.5 cm).

DISCUSSION

It has been suggested that many of the benefits of using ultrasound (increased local blood flow,[1,2] pain relief,[17,22] and increased wound healing)[8–10] are due to heating. There appear to be differing opinions regarding the desired temperature increases needed to enhance extensibility of collagen. Many investigators believe that optimal heating occurs when the tissue temperature rises above 40°C.[9,16] Others are of the opinion that an increase of 3° to 4°C above baseline temperature equals optimal heating.[1,6,12] Presently, no research can validate one opinion over another, but it is clear that the more vigorous the heating, the greater the chance is that collagen will elongate.

Neither thermistor depth in our study reached 40°C on an average (2.5 cm = 38.7° ± 1.6°C; 5 cm = 39.6° ± 1°C). Perhaps this can be explained by the increase in blood flow created by the thermal effects of ultrasound. The increase in temperature and blood flow engages the body's natural cooling mechanism. Therefore, it may be more difficult to heat muscle tissue as compared to the less vascular tendinous tissue.

We also observed that the baseline temperature of human muscle can vary from 3° to 4°C from subject to subject. If an individual's baseline tissue temperature is 32°C, an increase of 8° to 40°C is difficult to obtain. Due to these variations in baseline temperature from subject to subject, we believe that optimal heating may occur at less than 40°C.

Abramson et al[1] reported that ultrasound treatments achieving a 3°C increase (from a baseline of 36°C to an increase of 39°C) produced a marked increase in blood flow to the tissues. Lehmann[12] stated that slightly lower temperature increases of 1°C can reduce mild inflammation and increase metabolism, and that moderate heating (an increase of 2° to 3°C) will decrease pain and muscle spasm. Increasing tissue temperatures higher than 3° to 4°C above baseline will increase tissue extensibility, thus enabling the clinician to treat chronic connective tissue problems.[5,12]

Our data provide information on the rate that temperature drops following a 1-MHz ultrasound treatment. Because there was little variation in the rate of temperature decay at the two depths for the first two degrees (critical stretching window), we have taken an average of this rate and displayed it in Fig 3, along with the average heating rates of the two depths. This figure can assist the clinician by illustrating the average rate of temperature decay after 1-MHz ultrasound.

Heat Then Stretch

An increase in tendon extensibility is more apt to occur when the treatment is used in conjunction with stretching procedures.[3,11,15] This is because collagenous tissue is usually stiff and unyielding, but, once heated, it becomes much more pliable.[11,15] Showing that the same principle applied to muscle as well, Wessling et al[21] found that static stretching following ultrasound increased muscle extensibility by 20% over stretching alone. Therefore, when stress is placed upon heated tissue, greater and more permanent elongation results.

Aside from providing information on the rate of temperature decay after 1-MHz ultrasound, our data also outlined the optimal time to stretch the tissues. Gersten[11] and Lehmann et al[15] have reported that the ultimate time to elongate collage-

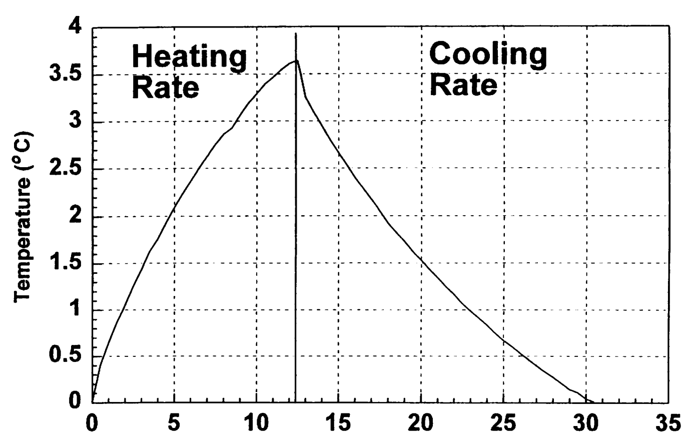

Fig 3. The average rate of temperature increase and decrease for the two depths via 1-MHz ultrasound.

nous tissue is at the peak of heating. With Lehmann's study,[15] this level occurred when the tissue reached a 3° to 4°C increase above baseline temperature. Wessling et al[21] also achieved marked increased in muscle extensibility by performing a 7-minute ultrasound treatment at 1.5 W/cm^2 to an area approximately six times the effective radiating area of the soundhead on the triceps surae muscle. We estimated that Wessling raised the temperature less than 2°C. We based this on our previous study[6] where we raised the temperature 4°C in 10 to 12 minutes at the same intensity, with a treatment size smaller than Wessling's (two effective radiating areas). Therefore, we believe that muscle temperature increases above 3°C, followed by stretching, produce favorable elongation within the tissue.

Duration of Therapeutic Heat

Just as opinions differ with respect to how warm the tissue must be for optimum stretching, opinions also vary regarding how long the tissue must stay heated. Some report that the temperature must reach and remain between 40° to 45°C for 5 minutes.[9,16] Our data indicated that the temperature drops much faster than this; thus, the stretching window remains open for a short time period. During the ultrasound treatment, at the 2.5-cm depth, the tissue temperature raised 4.0° ± 1.1°C. At the conclusion of the treatment, the temperature fell 1°C in only 2 minutes, 34 seconds. At the 5-cm depth, the temperature rose 3.5° ± 0.8°C, then decayed 1°C in only 2 minutes, 31 seconds. This demonstrated that the most effective time to encourage range of motion and stretching exercises within rigid tissues is actually less than 3 minutes following ultrasound treatments that raise the temperature >3°C. Stretching may be performed at a lower temperature; however, it will not be optimal. Therefore, it is probable that many clinicians perform ineffective heat and stretch therapy.

Stretch During Heat Application

We theorize that many clinicians wait too long following an ultrasound treatment to begin the stretching process. In the time it takes to remove the coupling agent from the patient and the ultrasound head, the temperature has already begun to drop. We propose that the most effective way to incorporate heat and stretch therapy into rehabilitation programs is to begin stretching during the last few minutes of the ultrasound treatment and to continue stretching through the next 2 to 3 minutes following the conclusion of the treatment. Obviously, this is more beneficial to the patient, because greater tissue elongation can be produced within a longer time frame. This also diminishes the risks associated with applying stress on a tissue cooled below the proper therapeutic level.[19,20]

Stretching Window: Two Depths Compared

Our data have also shown that target tissue depths between 2.5 cm and 5 cm are not significant when determining the initial rate of temperature decay. Preceding the ultrasound treatment, the deeper tissues recorded a higher baseline temperature than the more superficial tissues (36.1° ± 1.5°C as compared to 34.7° ± 1.1°C). During the treatment, the temperature of the superficial tissues did heat slightly faster than the deeper tissues; however, the time required to drop 1°C was nearly identical at each depth. As time passed, the deeper tissues cooled more slowly than the more superficial ones.

Stretching Window: 1 MHz and 3 MHz Compared

Perhaps the greatest difference in heating and cooling at various depths occurred between the deeper tissues reported in this study and the more superficial structures commonly treated with 3-MHz ultrasound. In 1995, we published the 3-MHz stretching window.[7] The results indicated that the tissues reached a therapeutic level in a shorter time period and, more critically, decayed significantly faster than our 1-MHz experiments. The temperature with 3 MHz dropped 1°C in 1 minute, 20 seconds compared to our 1°C drop in 2 minutes, 34 seconds using the 1-MHz ultrasound. Therefore, the ideal elongation period was cut nearly in half with the 3-MHz treatment. Clearly then, depth of ultrasound penetration is a crucial factor when determining the time of temperature decay when using a stretching window.

CLINICAL APPLICATION

Critics of our research pointed to the fact that we only measured rate of thermal increase and decay in muscle. However, Stolov et al[18] have reported that the muscle belly is more extensible than its tendon, with 95% of total elongation occurring within the muscle itself. Therefore, our data are especially beneficial when treating deep muscular conditions of the body, such as piriformis syndrome, chronic hamstring strains, or deep myofascial conditions. With this information, a clinician is better prepared to provide the most beneficial treatment to a patient afflicted with contractures and scar tissue buildup within a muscle. Because this study focuses on the temperature decay characteristics within muscle, further studies may be needed to determine the rate of temperature decay within tendons, joint capsules, and other tissues. This would provide us with a time frame for optimal use of friction massage on these structures.

ACKNOWLEDGMENTS

We thank Carolyn Billings for her assistance with the data collection and Dr. Mark Ricard for his statistical help. We also thank Physio Technology Inc (PTI) of Topeka, KS, for funding the project.

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