The Effects of Superficial Heating Before 1-MHz Ultrasound on Tissue Temperature

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Context: Ultrasound significantly raises tissue temperature, but the time of temperature elevation is short. Objective: To assess the effectiveness of superficial preheating on temperature elevation and decline when using ultrasound. Design: Within-subjects design to test the independent variable, treatment condition; repeated-measures ANOVAs to analyze the dependent variables, temperature elevation and decline. Setting: Athletic training laboratory. Intervention: Temperature at a depth of 3.75 cm was measured during ultrasound after superficial heating and with ultrasound alone. Subjects: 10 healthy men. Main Outcome Measure: Temperature was recorded every 30 s during 15 min of ultrasound and for 15 min afterward. Results: Temperature elevation with ultrasound was significantly greater with preheating (4.0 ± 0.21 °C) than with ultrasound alone (3.0 ± 0.22 °C). Temperature decline was not significantly different between preheating and ultrasound alone. Conclusions: Superficial preheating significantly increases temperature elevation but has no effect on temperature decline during a 15-min cooling period. Key Words: modalities, temperature decline, rehabilitation


One goal when using thermal ultrasound is to provide the appropriate intensity and duration of treatment necessary to significantly raise tissue temperature. Draper et al measured the rate of temperature rise in human muscle with a range of ultrasound intensities. They were the first to measure temperature increases at frequencies of both 1 and 3 MHz. The work of Draper et al provided clinicians with guidelines that would allow them to choose the size of the treatment area and the intensity, frequency, and duration of treatment that would raise tissue temperature, at a given depth, to a desired level.

A concern with ultrasound is that the thermal benefits are short-lived. Common ultrasound treatments use a fixed intensity throughout the treatment period, which results in a steady increase in tissue temperature. With higher intensity ultrasound treatments the rate of temperature elevation is so great that the treatment time is very short. If the treatment were to
continue the temperature would continue to increase to an intolerable level. Draper et al2 and Rose et al3 have shown that ultrasound treatments only allow short durations of temperature elevation within a prescribed range that occurs at the end of the treatment and for a few minutes afterward. This short duration of elevated temperature was described as an opportunity for stretching based on the findings of Lehman.4 who reported increased extensibility in rat-tail tendons that were stretched during periods of elevated temperatures. In making this conclusion, Lehman assumed that human muscle and connective tissue would respond in the same way as rat-tail tendon. The use of thermal ultrasound combined with stretching has also been shown to be more effective than stretching alone when treating human dorsiflexor tendons.5

With the termination of ultrasound application, heat begins to dissipate from the treated tissue. Some heat is lost to surrounding tissues through conduction.6,7 Hydrocollator™ moist-heat packs (Chattanooga Group, Inc, Hixon, Tenn) have been shown to significantly increase temperature of the superficial tissue layer.8 We hypothesized that heating the superficial tissue before ultrasound treatment would slow the subsequent cooling that occurs when ultrasound is terminated. This would increase the amount of time that temperature remains elevated. In addition, decreasing the heat dissipation that occurs during the treatment could increase temperature elevation. Therefore, the purpose of this study was to assess the effectiveness of superficial heating before ultrasound treatment on the subsequent temperature elevation and decline.

**Methods**

This study used a within-subjects design with the independent variable of treatment condition (ultrasound with superficial preheating or ultrasound alone). The dependent variables were temperature elevation and temperature decline. Subjects reported to an athletic training laboratory on a single day, where they were informed of the potential risks of the study and signed a consent form. The university’s institutional review board approved the study. Both treatments were given one after another on the same day to ensure that the microprobe thermocouple was at the same depth and treatment order was counterbalanced.

**Subjects**

Volunteers were screened for calf size and skinfold. The thickest portion of the calf from anterior to posterior was identified. The linear distance from the medial border of the tibia to the posterior portion of the calf and the skinfold of each subject were measured. Subjects with a calf size less than 7 cm or with a skinfold greater than 15 mm were eliminated to ensure that
each subject’s muscle mass was large enough to receive the thermistor probe and that the probe would penetrate well into muscle tissue. Ten healthy male subjects (age = 25.3 ± 3.6 years, height = 184 ± 0.07 cm, mass = 93.1 ± 19.3 kg, calf size = 8.8 ± 0.75 cm, calf skinfold = 10.4 ± 3.6) were accepted for this study.

**Procedures**

Subjects lay prone on an examination table while the skin over the medial head of the left triceps surae was shaved and cleaned with betadine surgical scrubs. The skin and underlying muscle were anesthetized with a 1-cc injection of 1% lidocaine that did not contain epinephrine. A microprobe thermocouple (MT-23/5, Physitemp Instruments, Clifton, NJ) was inserted horizontally into the medial belly of the left triceps surae at the location of greatest muscle mass (defined as the location with greatest distance measured from tibia to posterior calf). A T-shaped ruled instrument created by the primary investigator was used to guide the microprobe so that the temperature-sensitive tip was approximately 3.75 cm below the surface of the skin (Figure 1). This depth of 3.75 cm is the center of the depth of penetration range for 1-MHz ultrasound, which is assumed to be 2.5–5 cm.\(^1\) The microprobe was connected to an electrothermometer (BAT-10, Physitemp Instruments).

After a steady temperature was measured for 1 minute, that temperature was recorded as a baseline, and subjects received ultrasound under the 2 conditions. For the superficial preheating condition, Hydrocollator

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**Figure 1** The microprobe thermocouple is inserted to a depth of 3.75 cm below the skin’s surface with the aid of a T-shaped ruled instrument.
moist-heat packs were applied over the posterior calf for 20 minutes (Figure 2). The Hydrocollator temperature was maintained at 75 °C, and no pack was used more than once per day. Even though superficial temperature was not measured, it is reasonable to assume that superficial temperature increased when Hydrocollator moist-heat packs were used.8 For the ultrasound-only condition, temperature was required to return to the previously recorded baseline temperature before the application of ultrasound. After a baseline was measured and recorded for the ultrasound-only condition or after superficial heating, ultrasound was applied with a Forte™ 400 Combo (Chattanooga Group) via a 5-cm² sound head. The effective radiating area and beam-nonuniformity ratio reported by the manufacturer for the Forte 400 Combo were 4.6 cm² and <2.3–1, respectively.

A template twice the size of the sound head was centered over the microprobe tip, and the area within was covered with transmission gel. Continuous ultrasound was administered within the template at a frequency of 1 MHz and an intensity of 2.0 W/cm² (Figure 3). The sound head was moved in a longitudinal pattern within the template at an approximate speed of 3–4 cm/s. For the ultrasound-alone condition, ultrasound was administered with identical parameters. Temperature was allowed to return to baseline between trials, and the treatment order was counterbalanced. Temperature was continuously monitored and recorded every 30

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Figure 2  Superficial heat is provided to the posterior leg with a Hydrocollator™ moist-heat pack.
Ultrasound After Superficial Preheating

seconds during 15 minutes of ultrasound and for 15 minutes after ultrasound was terminated. Fifteen minutes was considered to be sufficient time for therapeutic intervention such as stretching.

After both trials were completed, the microprobe was removed and packaged for delivery to a local hospital to be gas sterilized (ETO) before being used again. The puncture wound was cleaned with isopropyl alcohol and covered with a sterile bandage.

**Data Analysis**

The means and SDs for temperature elevation during 15 minutes of ultrasound (difference between baseline and 15-minute temperatures) and temperature decline during 15 minutes after ultrasound was terminated (difference in temperature at termination of ultrasound and 15 minutes after ultrasound) were calculated. The means for temperature elevation and temperature decline were analyzed separately with repeated-measures ANOVAs using SAS System, version 8 (Cary, NC).

**Results**

Temperature elevation with ultrasound was significantly greater after preheating (Table 1; $F_{1,9} = 11.0, P = .005$), with mean temperature elevation of $4.0 \pm 0.21 ^\circ C$ after preheating and $3.0 \pm 0.22 ^\circ C$ with ultrasound alone. There was no significant difference in temperature decline ($F_{1,9} = 0.54, P = .41$),

Figure 3  The examiner administers continuous ultrasound within a template 2 times the size of the sound head.
with mean temperature decline of 2.2 ± 0.43 °C with preheating and 2.1 ± 0.60 °C with ultrasound alone. The temperature response is plotted in 1-minute increments in Figure 4. No treatment for any subject was cut short as a result of rapid or excessive heating.

### Discussion

Our results support those of Draper et al, who reported an additive effect of superficial heating before ultrasound; 0.84 °C higher at 3-cm depth compared with 1.0 °C at 3.75 cm in this study. These results, however, contradict the results of an earlier study by Lehmann et al, who reported no additive effect. The only real difference in these studies appears to be the duration of superficial heat application. In our study and the study of Draper et al, Hydrocollator moist-heat packs were applied for 15 minutes, as
opposed to only 8 minutes by Lehmann et al.\textsuperscript{7} The additional treatment time with the Hydrocollator moist-heat pack is apparently needed to produce the additive effects with ultrasound.

The magnitude of temperature elevation is important, but perhaps more important is the duration of temperature elevation. Simply raising temperature is not sufficient if there is no time for therapeutic intervention. Therapeutic heat can improve the extensibility of tendon,\textsuperscript{4} which can facilitate ROM increases during stretching. This facilitation will decrease, however, when temperature decreases. After ultrasound treatments are terminated the tissue will begin to cool immediately. Although Lehman et al.\textsuperscript{6,7} did not directly measure blood flow, they speculated that some heat will be absorbed and dissipated via blood circulation and some will be lost through conduction to surrounding tissue layers.

Fifteen minutes of hot-pack application did not heat the muscle at 3.75 cm (see baseline on Table 1 and Figure 4). The superficial heating was solely for the purpose of providing insulation for the deeper target tissue. Draper et al.\textsuperscript{9} reported a temperature increase of 0.74 °C with superficial preheating, but they were measuring temperature at a depth of 3.0 cm.

The duration of temperature elevation was greater in this study when superficial preheating was used. Fifteen minutes after ultrasound was terminated the temperature elevation with preheating was 0.9 °C higher than with ultrasound alone. This resulted from a higher temperature at the end of the ultrasound treatment rather than from a slower decline. Even though superficial preheating did not decrease temperature decline, it did result in a higher temperature at the end of the ultrasound treatment that remained higher for 15 minutes after the treatment, which is desirable.

The rate of temperature decline in this study was significantly less than that reported in the literature. Draper et al.\textsuperscript{2} and Rose et al.\textsuperscript{3} each reported rates of decline, but only Rose et al.\textsuperscript{3} measured temperature at depths similar to those in the present study. Rose et al.\textsuperscript{3} measured temperature at 2.5 and 5 cm and reported the length of time that it took for the tissue to decline every 1 °C. A 1 °C decline took an average of 2 minutes and 32 seconds for the 2 depths, compared with 4 minutes and 30 seconds in our preheated group. A 2 °C decline took an average of 6 minutes and 43 seconds, compared with 12 minutes in our preheated group. The slower temperature decline in our study was likely the result of a lower temperature at the end of the ultrasound treatment. This resulted in a smaller temperature gradient with the surrounding tissue, thus a slower rate of cooling. This is supported by the fact that it took even longer for our ultrasound-alone group (temperature declined 1 °C in 6 minutes and 2 °C in 14 minutes), in which temperature elevation was only 3 °C.

The original intent of our study was to raise temperature well above 3 °C in each experimental group and then measure the amount of time that the temperature remained more than 3 °C above baseline, similar to the studies by Draper et al.\textsuperscript{2} and Rose et al.\textsuperscript{3} The expected finding was that
temperature decline would be less in the group receiving superficial preheating; thus, temperature would remain more than 3 °C above baseline for a longer time. It was not possible to raise temperature to the level we desired, because the temperature elevation occurred much more slowly than in previous studies.\[^2,3\] Apparently there is a difference between the Forte 400 Combo that we used and the Omnisound 3000\[^\text{TM} \text{(Accelerated Care Plus, Sparks, Nev)}\] used in other studies. This was not the original intent of our study but has important clinical implications. The temperature elevations of 0.20 °C/min without preheating and 0.27 °C/min with preheating were substantially less than those found in other studies.\[^1,3,10-13\] The differences are magnified when one considers that the cited studies used an intensity of only 1.5 W/cm\(^2\), whereas we used a greater intensity of 2.0 W/cm\(^2\). The method of data collection was identical, and the treatment parameters and depths measured were very similar. In a recent study, my colleagues and I\[^14\] directly compared these 2 ultrasound units under identical conditions. Our results suggest that there is indeed a significant difference in the capability of these 2 units to raise tissue temperature. Using 3-MHz frequency and 1.0-W/cm\(^2\) intensity, we\[^14\] measured a rate of temperature elevation of 0.58 °C/min with the Omnisound 3000, compared with 0.39 °C/min with the Forte 400 Combo at a depth of 1.2 cm. Further research should compare other ultrasound units with the Omnisound 3000, which has been most widely studied.

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References


