Effects of Transducer Mass on Intramuscular Temperature During Ultrasound Treatments

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Context: A potential variable that could affect rate of temperature elevation with ultrasound is the pressure (mass) that is applied to the transducer head during application. Added pressure could compress the tissue, affecting density and the transmission of ultrasound energy. Little research has been completed to determine the effects of the amount of pressure applied during therapeutic ultrasound in vivo. Objective: To determine the effects of different applied transducer mass on intramuscular temperature during an ultrasound treatment within the left triceps surae. Design: Crossover clinical trial. Setting: Human performance research laboratory. Participants: Convenience sample of thirteen healthy, college-age students. Interventions: Three separate 3-MHz, 1.0-W/cm² ultrasound treatments were administered 1.5 cm within the triceps surae. The independent variables were the linear temperature standards (0.5°C, 1.0°C, 1.5°C, and 2.0°C above baseline) and the 3 different applied pressures measured in grams (200 g, 600 g, and 800 g). Main Outcome Measures: A thermocouple probe was used to measure triceps surae temperature, and time to reach the temperature standards was recorded during the ultrasound treatments. A 4 × 3 repeated-measures analysis of variance (RM-ANOVA) was used to analyze the differences for temperature points (0.5°C, 1.0°C, 1.5°C, and 2.0°C) and transducer mass (200 g, 600 g, and 800 g) and with respect to time. Results: The results of the RM-ANOVA showed no temperature-point and transducer-mass interaction ($F_{6,72} = 1.69, P = .137$) or main effect for mass ($F_{2,24} = 1.23, P = .309$). The time required to raise temperature 2°C was 209.1 ± 68.10 s at 200 g, 181.5 ± 61.50 s at 600 g, and 194.9 ± 75.54 s at 800 g. Conclusions: Under the conditions of this study, the amount of mass applied with the transducer during an ultrasound treatment does not ultimately affect the rate of tissue heating.

Keywords: tissue, pressure, thermal

Therapeutic ultrasound is a commonly used modality in athletic training. Ultrasound uses acoustic energy to generate heat in deep tissues by transmitting vibrations (mechanical waves) through a medium. The thermal effects include increased blood flow; increased macrophage activity, which decreases chronic inflammation; increased extensibility of tissue to decrease muscle spasms; and decreased joint stiffness. Past research has postulated that thermal temperatures that raise tissue temperature 1°C increase metabolic activity, increases of 2 to 3°C assist in decreasing muscle spasms and pain, and raising the temperature 4°C increases collagen extensibility and that the thermal effects are time dependent. The specific time to reach these benchmarks can vary by multiple factors such as size of the transducer, frequency, tissue depth, tissue type, size of the treatment area, and ultrasound intensity.

Less evident for tissue-temperature changes, however, is the effects of applied transducer pressure during ultrasound and how this pressure may affect tissue heating. Klucinec et al found that pressure influences the transmission of ultrasound acoustical waves. They determined that the optimal pressure for acoustic transmission was 600 g and that weight above 600 g appears to decrease acoustical transmission. Gann examined ultrasound applied pressure and temperature changes in a simulated model between 600 and 1500 g and found that the rise in temperature was not affected in a gel model. However, clinician pressure varies when applying ultrasound. Gann et al found that physical therapy students only apply a mean pressure of 119.83 g and that experienced physical therapists applied a mean pressure of 193.60 g; both fall over 400 g short of the 600-g optimal pressure. Klucinec et al and Gann et al stated that the effects of pressure and temperature changes during ultrasound through gel pads may be different in human tissues. To our knowledge, no known ultrasound studies have considered transducer pressure when examining heating rates in vivo, although a study of this magnitude was recommended by the aforementioned authors.
Finding the optimal pressure for thermal effects during ultrasound treatments may affect heating characteristics and alter ultrasound-treatment time parameters in the clinical setting. Therefore, the purpose of this study was to further investigate the effects of applied pressure on intramuscular temperature during a therapeutic thermal ultrasound treatment. Temperature ranges in 0.5°C increments, from 0.5°C to 2.0°C, were chosen based on increased metabolic activity and pain reduction as referenced by aforementioned studies. Our hypothesis was that 600 g of applied pressure would produce greater heating than the average pressure applied by clinicians (about 200 g) or pressure greater than the recommended pressure (800 g) during an ultrasound treatment.

Methods

Design
This study was an experimental design. The independent variables were the linear temperature standards (0.5°C, 1.0°C, 1.5°C, and 2.0°C above baseline) and the 3 different applied pressures measured in grams (200 g, 600 g, and 800 g) on the dependent variable of time to reach these temperatures in intramuscular gastrocnemius tissue 1.5 cm below the surface.

Participants
Thirteen healthy, college-age students volunteered for this study (6 men, 7 women; height 170.03 ± 9.86 cm, mass 71.96 ± 16.2 kg, skinfold 12.79 ± 5.5 mm, calf circumference 35.5 ± 6.9 cm). Those with a lower leg injury in the past 6 months or any contraindications to ultrasound were excluded. Treatment order was randomly assigned using a Latin-square technique. The number of participants was chosen based on a preliminary power analysis using means and standard deviations of previous research. Before participating in this study, each participant read and signed a consent document approved by the human subject institutional review board.

Instrumentation
An Omnisound 3000C (Accelerated Care Plus, Reno, NV, 230305E) with a 5-cm² transducer was used to deliver ultrasound. The effective radiating area was 4.1 and BNR 4.5:1. The ultrasound transducer was modified to hold metric weights (mass) measured in grams (Figure 1). A Thermes USB data-acquisition instrument (Thermes USB, Physiotemp Instruments Inc, Clifton, NJ) was used to record both temperature and time (in seconds; Physiotemp Instruments Inc MT-26/4). A modified carpenter square contoured to the shape of a calf was used to determine the correct insertion point for the thermocouple (Figure 2). A rectangle with rounded ends 7.2 cm in length and 3.6 cm in width (the size of 2 transducers placed side by side) was placed over the treatment area.

Skinfold calipers (Country Technologies Inc 68900) were used to determine skinfold thickness, and a measuring tape was used to determine circumference of the gastrocnemius. A metronome (Seiko S-Yard Co DM-50) was used to help maintain a constant transducer velocity of 3.5 cm/s within the template to control for speed consistency.

Procedures
Before the beginning of the study, the lead investigator simulated an ultrasound treatment on a digital scale to ensure that pressure was maintained during an ultrasound treatment. Each transducer-mass practice trial was conducted a minimum of 3 times on the scale before and once a week during the data-collection period. While no data
were collected while practicing, the investigator easily stayed within the desired range, which was ±10 g of the designated weight.

The left gastrocnemius was shaved, and skinfold and girth measurements were taken at the widest part of the calf. The carpenter’s square was used at the widest part of the medial aspect of the left gastrocnemius to locate the thermocouple insertion at a depth of 1.5 cm below the apex of the left medial gastrocnemius. The tip of the 4-cm thermocouple was in the center of the treatment area, which was found by measuring the distance from the insertion point to the middle of the template placed on top of the left medial gastrocnemius. Before probe insertion, the treatment and insertion areas were thoroughly cleansed using 70% isopropyl alcohol pads. The insertion area was then sprayed with ethyl chloride (Cramer Cold Spray, Cramer Products Inc) to partially numb the area of insertion. A 26-gauge, 4-cm-long thermocouple needle (Physiotemp Instruments Inc MT-26/4) was inserted. The thermocouple was connected to a Thermes USB data-acquisition device, which measured the temperature at the tip of the thermocouple and time.

Temperature was recorded in 10-second increments throughout the study. After all measures and thermocouple insertions were performed, 5 mL of ultrasound gel (Sonigel Mettler Electronics Corp, Anaheim, CA) was applied to the treatment area. Baseline intramuscular temperature was recorded after 10 minutes for each subject. At the 10-minute mark, the data-acquisition system reset the time to zero and the ultrasound treatment began. The ultrasound was administered with 1 of the 3 masses (200 g, 600 g, and 800 g) depending on treatment order. These masses were selected to represent reported clinician average pressure (200 g), optimal pressure from a previous study14 (600 g), and excess pressure (800 g) that has been shown not to effect temperature.13 The transducer was moved at a consistent speed of 3.5 cm/s with the aid of a metronome set at 60 beats/min. The same investigator performed all treatments.

All 3 treatments occurred during 1 visit. Each of the 3 treatments continued until the intramuscular temperature increased 2°C from the subject’s initial baseline temperature measurement. The intramuscular temperature was then allowed to return to the initial baseline temperature for 10 seconds before the subsequent treatment was initiated, which varied between subjects. After each treatment, the remaining ultrasound gel was removed, and then 5 mL of gel was reapplied. All treatments followed the same ultrasound setting parameters and testing procedures, with the exception of transducer mass. After the last ultrasound treatment, the thermocouple was removed and the subject’s leg was cleansed and bandaged. The thermocouple was disinfected by soaking it in CidexPlus 3.4% glutaraldehyde solution (Johnson & Johnson Co, Irving, CA) for at least 24 hours before reuse.

### Statistical Analysis

A 4 × 3 repeated-measures analysis of variance (RM-ANOVA) was used to analyze the differences for temperature points (0.5°C, 1.0°C, 1.5°C, and 2.0°C) and transducer mass (200 g, 600 g, and 800 g) and with respect to time. The statistical analysis was performed using Statistical Package for Social Sciences (SPSS version 17, Chicago, IL). The alpha level was set a priori at $P < .05$ to minimize type I errors.

### Results

The mean baseline temperature for all subjects was 35.88 ± 0.49°C. Descriptive statistics for time to reach each temperature point and total temperature with respect to mass are presented in Tables 1 and 2. The results of the RM-ANOVA showed no temperature-point and transducer-mass interaction ($F_{6,72} = 1.69, P = .137$) or main effect for mass ($F_{2,24} = 1.23, P = .309$) but did show a significant main effect for temperature point ($F_{3,36} = 128.25, P < .001$, with all temperature points significantly different from each other ($P < .05$).

### Discussion

There are several factors that affect transmission and rate of heating during an ultrasound treatment, including depth, frequency, and intensity of the ultrasound; rate of temperature raises; and tissue type as reported in the literature,1,8–13 but there is limited information on the pressure of the transducer on in vivo temperature changes. One study found that 600 g was the optimal pressure applied during an ultrasound treatment for effective heating,14 while another refuted that finding.13 Our data showed that the amount of mass on the transducer did not have any significant effects on

### Table 1  Mean Heating Rate by Mass at 200, 600, and 800 g in 0.5°C Increments

<table>
<thead>
<tr>
<th>Temperature range</th>
<th>Heating rate at 200 g</th>
<th>Heating rate at 600 g</th>
<th>Heating rate at 800 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–0.5°C</td>
<td>0.705°C/min</td>
<td>0.761°C/min</td>
<td>0.844°C/min</td>
</tr>
<tr>
<td>0.5–1.0°C</td>
<td>0.594°C/min</td>
<td>0.763°C/min</td>
<td>0.546°C/min</td>
</tr>
<tr>
<td>1.0–1.5°C</td>
<td>0.502°C/min</td>
<td>0.630°C/min</td>
<td>0.623°C/min</td>
</tr>
<tr>
<td>1.5–2.0°C</td>
<td>0.530°C/min</td>
<td>0.542°C/min</td>
<td>0.532°C/min</td>
</tr>
<tr>
<td>0–2.0°C</td>
<td>0.573°C/min</td>
<td>0.661°C/min</td>
<td>0.615°C/min</td>
</tr>
</tbody>
</table>
intramuscular-temperature time difference during an ultrasound treatment. However, the time to raise intramuscular temperature 2°C at 200 g was 209.08 seconds and at 600 g was 181.54 seconds, which is consistent with Klucinec et al’s' findings that 600 g may be optimal for better acoustical transmission and quickening the time to reach the temperature point.

We also hypothesized that the temperature would increase faster with increased pressure due to interstitial fluid being pushed out of the tissue, theoretically compressing some of the extracellular fluids into the surrounding tissues, creating less fluid under the transducer to disperse heat. We found that 600 g was quickest in terms of reaching a 2°C increase and that the heating rate for 600 g was the fastest at each 0.5°C interval, but this difference was not significant compared with other masses (Table 1). Our heating rate per minute, measured over the entire 2°C interval, was 0.57°C at 200 g, which is consistent with Drapers et al’s’ heating rates per minute of 0.58°C/min at 1.6 cm. We expected to find this similar heating rate at 200 g since this pressure is the average pressure applied by clinicians. The overall heating rates per minute for 600 g (0.66°C/min) and 800 g (0.62°C/min) were slightly faster, probably a result of the heavier transducer mass pushing interstitial fluids out of the area, which warrants further attention.

Another aspect that may have confounded our results is blood flow. While not measured, blood flow in the treatment site may have affected temperature changes. Heat produced via ultrasound can be dissipated by the blood flowing through the tissue. The amount of blood flowing depends on the diameter of the vessels. When external pressure is applied via the ultrasound transducer head, vessels in that area should collapse to some degree, thus decreasing blood flow to and from this area. We expected to see a decrease the amount of heat dissipated during an ultrasound treatment due in part to the occlusion of blood flow in the area directly under the transducer head, especially with a heavier transducer head (800 g). With the body’s ability to dissipate heat via blood flow hindered, we hypothesized that heating at the heavier masses (600 and 800 g) would become more vigorous. Our study did not directly support or refute this hypothesis, possibly due to the transducer’s being in constant motion limiting the effects of pressure in 1 specific location in the ultrasound treatment area or to the fact that the pressures selected were too close in range to show dramatic changes.

The exact depth of heating may have been slightly adjusted due to the distance between the transducer and the thermocouple in each participant. We also observed that lean individuals had less tissue compression at every given pressure. In individuals with more subcutaneous fat, there appeared to be more tissue compression, which may have affected the exact location of the thermocouple. We are not suggesting that subcutaneous tissue directly affects heating, which would be contrary to Grotthus-Draper. Instead, we are suggesting that the heavier the mass of the transducer, the more easily fat is compressed, resulting in less distance between the thermocouple and transducer. Thus, effectively we were measuring at a lesser depth of penetration in those with thicker adipose tissue.

Further research is warranted to determine the effects of pressure and heating with ultrasound controlling for subcutaneous tissue thickness.

### Conclusion

Previous research conducted on gel models in the laboratory setting revealed that there may be an optimal pressure that should be applied during ultrasound for better acoustical transmission, but results have been inconsistent. In intramuscular tissues, we found that the transducer mass has limited effects on the time it takes to reach specific temperature points, suggesting that currently other factors such as the range of transducer mass, skinfold thickness, and frequency and intensity of ultrasound treatments need to be further investigated. Until then, we do not believe that clinicians need to factor pressure into ultrasound treatment parameters for altering heating effect in tissues.

### References