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Research article

Intramuscular temperature differences between the mid-point and peripheral effective radiating area with ultrasound

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Abstract
The purpose of the study was to determine whether uniform intramuscular heating is achieved throughout a treatment area 2 times the transducer head at both 1 and 3 MHz. Seven male and three female subjects (Age: 23.6 ± 1.0 yrs, Weight: 83.8 ± 23.2 kg, Site Skinfold: 13.9 ± 7.3 mm) underwent two ultrasound treatments (1 and 3 MHz) in the triceps surae muscle group. Thermocouples were inserted at the midpoint and periphery of the treatment area. Ten minute baseline temperatures were recorded followed by a ten minute ultrasound treatment. Two (site) X 10 (time) repeated measures ANOVAs were separately used to determine significance for 1 and 3 MHz treatments. Post-hoc testing was performed using the Bonferroni adjustment. A significant site-by-time interaction was observed for both the 1 and 3 MHz treatments. From baseline to the end of the treatment, temperature increased approximately 2.62°C and 1.58°C for the midpoint and periphery of the 1 MHz treatment and 5.88°C and 3.64°C for the 3 MHz treatment. The differences in temperature suggest that uniform heating does not occur throughout the treatment area.

Key words: Tissue, thermal effects, acoustical.

Introduction

Ultrasound is both a non-thermal and thermal modality which utilizes acoustic energy to promote healing (Prentice, 2003). Its non-thermal effects include collagen alignment (Byl et al., 1993; da Cunha et al., 2001), increased collagen and wound strength (Byl et al., 1993) acoustic streaming (Garrett et al., 2000; Kramer, 1984), cavitation (Prentice, 2003), decreased nerve conduction velocity (Kramer, 1984), peripheral nerve regeneration (Raso et al., 2005), bone fracture repair (Stein and Lerner, 2005; Warden, 2003), accelerating ligament healing (Warden et al., 2006), and edema reduction (Prentice, 2003). The thermal benefits of ultrasound include the treatment of muscle pain (Almeida et al., 2003), increased elasticity of both muscle and tendon (Chan et al., 1998; Draper et al., 1998; Draper and Ricard, 1995; Rose et al., 1996), increased tensile strength and energy absorption in tendons (Enwemeka, 1989), increased passive range of motion in joints (Knight et al., 2001), increased nerve conduction velocity (Kramer, 1984), increased ligament repair time (Leung et al., 2006), increased blood flow (Noble et al., 2007), and increased active range of motion in joints (Oates and Draper, 2006).

Thermal effects are often used to increase range of motion (Draper et al., 1998) and extensibility of collagen tissue (Chan et al., 1998; Draper and Ricard, 1995; Rose et al., 1996), therefore, it is imperative that the treatment area reach the critical temperature value in order to produce the desired physiological effects to lengthen these tissues. Previous research has suggested that a 3-4°C increase from baseline temperature is needed to increase tissue extensibility (Castel, 1993; Draper et al., 1995; Oates and Draper, 2006). If the goal is to increase the extensibility of tissue, it is crucial to heat the entire treatment area to cover as much connective tissue as possible to produce these desired effects. To our knowledge, only three studies (Fincher et al., 2007; Garrett et al., 2000; McCutchan et al., 2007) examined the differences in site (middle and proximal/distal) and found no temperature differences. However, two (Fincher et al., 2007; McCutchan et al., 2007), used an Autosound™ with different intervention methods and one measured the temperature distances over 40 times the effective radiating area (ERA) (Garrett et al., 2000).

Most clinicians apply ultrasound within their specific treatment area, often moving the transducer head in circular or longitudinal strokes in the middle of the treatment site more frequently than the outer edges. This pattern of movement will theoretically result in more transducer strokes in the middle of the treatment area versus the peripheral sites, affecting the temperature of the entire treatment area. Therefore, the purpose of our study was to determine if there is uniform intramuscular heating between the midpoint and periphery of a treatment area 2 times the size of 5cm^2 traducer head during ultrasound treatments. Uniform heating is defined as the entire treatment site having the same temperature. We hypothesized that the midpoint of the 1 and 3 MHz treatment areas will have higher intramuscular temperatures compared to the periphery due to the higher occurrence of the transducer head moving across the middle of the treatment site.

Methods

Subjects

Ten subjects, seven male and three females (23.6 ± 1.0 years, height: 1.74 ± 0.09 m, weight: 83.8 ± 23.2 kg, skinfold thickness: 13.9 ± 7.3 mm, calf circumference: 37.7 ± 4.5 cm) volunteered for the study. Subjects were verbally screened for prior history of trauma to the leg, recent leg injuries within the past 6 months, infection, and vascular or nervous conditions. The number of subjects was based on a power analysis completed prior to recruitment using the means and standard deviations of

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previous research (Ashton et al., 1998; Bishop et al., 2004; Burr et al., 2004; Chan et al., 1998; Draper et al., 1995; Myrer et al., 2001; Oshikoya et al., 2000; Rose et al., 1996). The procedures of this study were approved through the Human Subjects Institutional Review Board and informed consent was obtained prior to subject participation.

Instruments

An Omnisound 3000 (Accelerated Care Plus, Reno, NV) ultrasound unit with a beam non-uniformity ratio of 2:1 for 1 MHz and 3:1 for 3 MHz was used for both frequencies. Using the 5-cm² sound head, a rectangular template was made to measure an area of two times the sound head, or approximately 7.2 cm x 3.5 cm. For the coupling medium, we utilized Aquasonic coupling gel (Parker Laboratories, INC, Fairfield, NJ) at a consistent temperature of 22.4°C ± 0.43°C for the 1 MHz and 3 MHz treatments. Ambient temperature was recorded using a portable thermometer (Omega Microprocessor Thermometer, Stamford, CT). Intramuscular temperatures were measured using two, 26-gauge, 4 cm long thermocouple needles (MT-26/4 hypodermic needle microprobe, Physitemp, Clifton, NJ) connected to an electrothermometer (Iso-Thermex, Columbus Instruments, Columbus, OH) that recorded temperatures at 1 minute intervals. We utilized a template that fit around the calf muscle and measured depth in centimeters to determine the point of entry for each thermocouple needle (Figure 1).

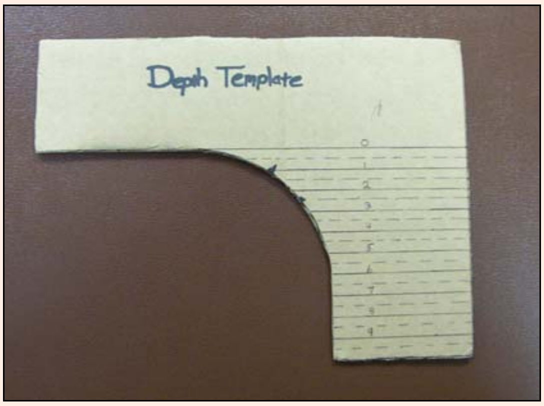

Figure 1. Customized template for measuring depth on the triceps surae muscle group.

Procedures

Our treatment table was set up in a room with an ambient temperature of 22.3°C ± 0.4ºC. With the subjects lying prone, we determined the widest part of the calf muscle and placed the treatment template on the surface of the calf. We found the middle of the template then placed the depth template to mark the insertion for the first thermocouple needle (2.5 cm for the 1-MHz treatment, and 1.0 cm for the 3-MHz treatment) to stay within depths commonly used as guides when performing ultrasound treatments (Prentice, 2003). We aligned the depth template along the distal edge of the rectangular template and marked the second insertion point based upon the depth targeted. The template was aligned so that when the probes were inserted to the maximal length, it fell within the middle of the template. The probes were placed approximately 3.6 cm apart within the template area (Figure 2).

Figure 2. Outline of treatment area template and markings for probe insertions on the triceps surae.

Both the treatment area and the thermocouple insertion marks were shaved, cleansed with a 0.40% benzalkonium chloride antiseptic towelette**,** and re-cleansed with a 70% isopropyl alcohol wipe. We inserted the entire 4 cm length of the thermocouple needles, one at the midpoint and the other at the periphery or distal end of the treatment site. Once connected to the electrothermometer, a 10-minute baseline period began and temperatures were recorded. The patients were in this position for study preparation and baseline measurements for approximately 30 minutes prior to the beginning of data collection. The ultrasound treatment parameters were set according to previous literature, 1 MHz at 1.5W/cm², continuous, for 10 minutes (Ashton et al., 1998; Draper et al., 1995; Rose et al., 1996) and 3 MHz at 1.0W/cm², continuous, for 10 minutes (Bishop et al., 2004; Draper et al., 1995; Leung et al., 2006). A one minute transition period between the baseline and the treatment was used to apply the coupling gel. Movement of the transducer head was timed to 4 cm/sec (Draper, 1998; Weaver et al., 2006), using a metronome (Yamaha QT-1 quartz metronome) in longitudinal patterns across the template, ensuring that the edges of the treatment area were covered. Intramuscular temperatures were recorded every minute from the beginning of baseline to the end of the treatment time. All subjects completed the 1 MHz ultrasound treatment first, followed by the 3 MHz treatment with a minimum of 48 hours between treatments. The subjects were not counterbalanced since the 3 MHz treatment was HSIRB approved and initiated several days after the original study of just measuring 1 MHz differences.

At the end of the treatment, the coupling gel and thermocouple needles were removed and the area recleansed with a 70% isopropyl alcohol wipe then soaked and cleaned with Cidex OPA (Johnson & Johnson, Irvine, CA) as recommended by the manufacturer. Standard adhesive medical strips were applied to the thermocouple insertion points and subjects were instructed on the use of ice to relieve muscle soreness if occurred.

Statistical analysis

We used a 2X10 ANOVA with repeated measures to determine differences in intramuscular temperature between the two measurement sites (midpoint and

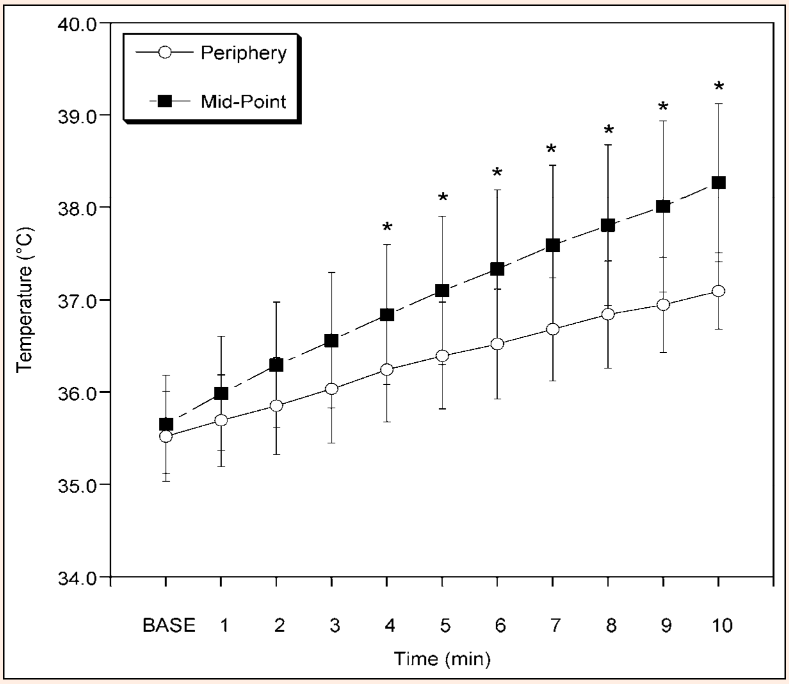

Figure 3. The response in temperature at the midpoint and the periphery during 1 MHz ultrasound treatment (M ± SD). * denotes significant difference between midpoint and periphery at the respective time point, p < 0.0045.

periphery) and time (minutes 1 through 10) for both 1 MHz and 3 MHz ultrasound treatments separately. All statistical testing was conducted using the Statistical Package for Social Sciences (SPSS version 14.0, Chicago, IL). The alpha level was set *a priori* at $p < 0.05$ to minimize type I errors. In the case of significant interactions, post-hoc testing was performed using a simple effects analysis with the Bonferroni adjustment at $p = 0.0045$. All data is presented as mean ± standard deviation units.

Results

The responses in temperature within the middle and peripheral treatment sites during both 1 and 3 MHz frequency ultrasound treatments are illustrated in Figures 3 and 4, respectively. The two way repeated measures ANOVA for the 1 MHz treatment revealed a site by time interaction, ($F_{10,90} = 25.66$, $p < 0.001$, partial eta squared = 0.740). Post-hoc testing revealed that the temperature

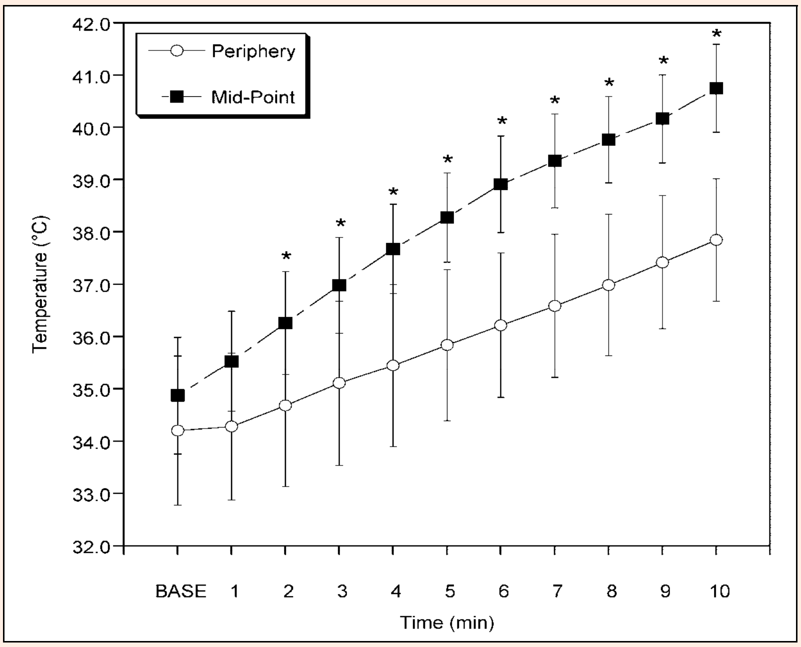

Figure 4. The response in temperature at the midpoint and the periphery during 3 MHz ultrasound treatment (M ± SD). * denotes significant difference between midpoint and periphery at the respective time point, p < 0.0045.

at the midpoint was reater than the periphery at all time points except for baseline and minutes 1 through 3 of the treatment. From baseline to the end of the treatment (10 min), temperature increased approximately 2.62°C at the midpoint and 1.58°C for the periphery.

The two way repeated measures ANOVA for the 3 MHz treatment revealed a site by time interaction, ($F_{10,90}$ = 16.66, $p<0.001$, partial eta squared = 0.649). Post-hoc testing revealed that the temperature at the midpoint was greater than the periphery at all time points except for baseline and minute 1 of the treatment. From baseline to the end of the treatment (10 min), temperature increased at the midpoint approximately 5.88°C and 3.64°C for the periphery.

Discussion

Our midpoint temperature increased approximately 2.62ºC above the baseline in the middle of the treatment area with a rate of 0.262°C per minute for the 1 MHz treatment which is lower than results of previous research (Burr et al., 2004; Draper et al., 1995; Weaver et al., 2006). This may be explained by the variability of tissue types of the subjects. Our thermocouple placements may not have been consistently placed within the muscle tissue at both the midpoint and peripheral areas at the same depth because we only measured skinfold at the middle of the treatment area. It may be prudent to measure skinfold sites at both the midpoint and periphery sites to ensure that depth placement is consistent as the calf becomes narrower toward the distal treatment sites. In addition, at the periphery, we had a total increase from baseline only 1.58°C at a rate of 0.158°C per minute, suggesting that the periphery of the treatment site for 1 MHz did not reach the desired therapeutic effect and ranges as noted by previous research for tissue extensibility (Castel, 1993; Draper et al., 1995; Oates et al., 2006). However, our heating rates were based upon total time divided by total temperature increase and recent evidence suggest (Demchak et al., 2007) that heating rates per unit of time are curvilinear, not linear. More time may be needed for the periphery to reach the critical level and thus change the length of time ultrasound treatments are required for the treatment site to be uniformly heated.

For our 3 MHz treatment, at 1.0 W/cm^2 for 10 minutes, we achieved an averaged increase of 5.88°C at a rate of 0.588°C per minute at the midpoint and an averaged increase of 3.64°C with a rate of 0.364°C per minute at the periphery. Our temperature increases supports current literature (Draper et al., 1995; Draper and Ricard, 1995), which states that intramuscular temperatures can be raised an average of 5.3°C using 3 MHz for ten minutes. However, it differs with the heating rate on tendons at a rate of 2.1°C/min (Chan et al., 1998). Our peripheral probes were placed distally to the midpoint, closer to the musculotendinous junction of the triceps surae muscle group that may have accounted for temperature differences as a result of change in tissue density from muscle to tendon. Of importance is that although the periphery was 2.24°C below the mid point at the end of the 3 MHz treatment, it was still within the desired therapeutic range for vigorous heating (3-4°C) in order to facilitate tissue extensibility.

We used a treatment site 2 times the transducer head for both ultrasound treatments because most clinicians and researchers have commonly used this method of determining the treatment area (Holcomb, 2003; Holcomb and Joyce, 2003; Merrick et al., 2003; Noble et al., 2007), and it closely approximates a 2-3 ERA site used in previous studies (Ashton et al., 1998; Bishop et al., 2004; Byl et al., 1993; Draper et al., 1995; Gallo et al., 2004; Rose et al., 1996). Knowing that the ERA is somewhat less than the treatment area and that we did not have access to a digital power meter to specifically measure the ERA, we made sure to cross the edges of the treatment site by approximately 1-3 millimeters. These factors may explain the differences in our midpoint and peripheral temperatures. Our peripheral edges may not have received all the ultrasound energy and resulted in less temperature increases compared to the mid point where we were assured that the ultrasound energy was delivered. McCutchan et al. (2007) found no difference between sites, however, their thermocouples were placed approximately 2.9 cm apart which may have been too close to the midpoint to detect a difference. They also used an Autosound™ unit which does not utilize stroke/transducer head movement. Future studies should also record temperatures from the midpoint of the ERA to the periphery segmentally by centimeters to help determine exactly where in the treatment site temperature uniformity subsides.

The difference in intramuscular temperatures found between midpoint and periphery in our study may also be linked to the stroke count across the mid point versus the periphery or transducer velocity over the treatment area. Since the midpoint of the treatment site received more stroke counts than the periphery, it is understandable that the midpoint had higher temperatures. We used a metronome to provide a constant rhythm for us to follow over the treatment area at a rate of 4cm/s as recommended by previous research to provide even distribution of sound waves to control for transducer velocity (Bishop et al., 2004; Demchak et al., 2007; Draper, 1998; Draper et al., 1998). However, recent evidence suggests that transducer velocity does not alter intramuscular heating temperatures (Weaver et al., 2006). By experimenting with velocities of 2-3cm/s, 4-5cm/s, and 7-8cm/s, the researchers found that intramuscular temperatures after each change in velocity were within 1ºC of each other based upon midpoint measurements. We used longitudinal strokes in our study but many clinicians use either longitudinal, circular, or a combination of both when performing ultrasound treatments. The specific type of stoke used for applying ultrasound should be investigated further.

The intramuscular temperature differences may also be a component of the specific type of ultrasound unit used. In accordance with the majority of the literature (Byl et al., 1993; Draper et al., 1995; Gallo et al., 2004; Garrett et al., 2000; Holcomb and Joyce, 2003; Oshikoya et al., 2000; Weaver et al., 2006), we used the Omnisound 3000 to maximize energy delivery. While the Omnisound 3000 has been shown to heat more efficiently than the Forte 400 Combo (Holcomb and Joyce, 2003), the heating effects delivered by other similar ultrasound units may vary (Johns et al., 2007a; 2007b), and further investigation into the differences among types of units as they relate to uniform heating throughout the ERA should be conducted.

Conclusion

When the goal is to improve extensibility via vigorous heating, it is important that the temperature is elevated by 3-4°C throughout the treatment area. We found that 3 MHz, using standard parameters effectively achieved the desired therapeutic range at the midpoint and the periphery, suggesting that all the tissues in the treatment area met the 3-4°C critical value and would respond accordingly to stretching or elongation as desired. However, when using 1 MHz, we found that the periphery did not reach the critical temperature ranges. These results suggest that using ultrasound for heating deeper tissues within the desired therapeutic range of 3-4°C did not occur for 1 MHz and that all the tissues in the treatment area may not respond therapeutically as desired. If the goal is to produce deep heating in tissues uniformly, clinicians may need to select other modalities that can achieve these effects.

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Key points

- 3 MHz is more effective in raising intramuscular temperature within ERA.
- Stroke count/rate of transducer may play a factor in heating tissue.
- Treatment size may alter uniform heating.

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