Temperature Change in Lumbar Periarticular Tissue With Continuous Ultrasound

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Study Design: Counterbalanced, within-subjects experimental design.

Objective: To determine the effect of continuous 1-MHz ultrasound, given at 1.5 W/cm² and 2.0 W/cm² for 10 minutes, on tissue temperature in the region of the L4-L5 zygapophyseal joint.

Background: Ultrasound is a modality commonly used for the treatment of lower back pain syndromes. Randomized controlled trials supporting the clinical effectiveness for ultrasound in the treatment of any type of lower back condition are lacking. While one purported purpose of ultrasound is the deep-heating effect, it has not been demonstrated that ultrasound can heat tissues in the area of the lumbar zygapophyseal joints, and the specific parameters needed for a heating effect have not been investigated. To aid in the design of the ultrasound intervention for future randomized controlled trials, it would be beneficial to have insight into the thermal effects of ultrasound on tissues of the lumbar spine and the parameters needed to produce a thermal effect. The present study examined the heating effect of ultrasound on periarticular tissue in the lumbar spine.

Methods and Measures: Continuous, 1-MHz ultrasound at intensities of 1.5 W/cm² and 2.0 W/cm² was applied for 10 minutes to the lower back of 6 healthy individuals without lower back pain, while temperature measurements were taken with a hypodermic thermocouple implanted next to the L4-L5 zygapophyseal joint. ANOVA models were used for statistical analysis.

Results: Statistical analysis confirmed that the 2.0-W/cm² ultrasound application produced (a) a more rapid increase in temperature over time, (b) a greater overall level of heating, and (c) significantly greater heating 6 minutes after the beginning of ultrasound administration. The mean terminal temperatures (at 10 minutes) obtained during the 1.5-W/cm² and 2.0-W/cm² ultrasound applications were 38.1°C and 39.3°C, respectively.

Conclusion: Continuous 1-MHz ultrasound given at either 1.5-W/cm² or 2.0-W/cm² intensity has the capability of heating lumbar periarticular tissue. The higher-intensity ultrasound resulted in greater and faster temperature increase. J Orthop Sports Phys Ther 2004;34:754-760.

Key Words: heat, low back, lumbar spine, physical agents

Therapeutic ultrasound is classified as a deep-heating modality when used in a continuous mode, and unlike the more superficial heating modalities, 1-MHz ultrasound has been shown to produce thermal effects to a depth of 5 cm. The resulting tissue temperature elevation is believed to contribute to a therapeutic benefit. Ultrasound will heat both skeletal muscle and collagenous structures such as joint capsule and tendon. The reported therapeutic benefits attributed to temperature elevation include pain reduction, decreased joint stiffness, tissue healing, and alterations in collagen extensibility. Many of the studies investigating therapeutic ultrasound have focused on the heating effect. These studies have been performed on both animal models and humans, and have involved peripheral areas of the body. To our knowledge, an investigation into the heating effect of continuous therapeutic ultrasound on tissues of the lumbar spine has not yet been reported.

While therapeutic ultrasound is used for the treatment of painful conditions involving the lumbar
spine, there is currently insufficient evidence to support its use for this purpose. Several reports have been published that examine the therapeutic effect of ultrasound on individuals with lower back pain believed secondary to disc prolapse. Nwuga studied the use of ultrasound in 73 individuals with a diagnosis of acute prolapsed intervertebral disc in the lumbar spine. Diagnostic classification was based on myelographic and electrodiagnostic studies, diminished deep-tendon reflexes, and a straight leg raise limited to 40° or less. All subjects were treated with bed rest. Many of the treatment parameters for the ultrasound intervention were not reported, but the intensity used was reported as between 1 to 2 W/cm² given over a 10-minute duration, with a mean of 11 treatments. The ultrasound treatment group demonstrated a statistically significant improvement in self-rated pain, spinal range of motion, and straight leg raise range of motion over control and placebo ultrasound groups. Gnatz provides contrasting results for case studies where ultrasound was used to treat individuals with suspected disc prolapse.

The majority of the human studies concerning the heating effect of therapeutic ultrasound have been performed on the triceps surae muscles. The area for deepest (5 cm) temperature measurement in the triceps surae has been a region that is within 1 cm from the bone, creating the potential for reflection of the ultrasound to further enhance the heating effect. There is a gap in the literature concerning the ability of ultrasound and the parameters to use to produce a similar heating effect in the region of the lumbar zygapophyseal joints, an area that has been implicated as a source of pain or dysfunction associated with lower back pain. Although we suspect that temperature increase in the region of the zygapophyseal joint will occur in a manner similar to the triceps surae, the presence of a dense thoracolumbar fascia, which is high in collagen content, and an irregular-shaped lumbar articular column with the zygapophyseal joints at the edge of the column may lead to a different situation for the production of heat. Knowing that different body regions may heat at different rates in response to ultrasound, and because the body is anisotropic and nonhomogeneous, it appears important to have specific data concerning heating with ultrasound that is germane to the articular region of the lumbar spine, and to understand how treatment parameters influence heating. These data would then be useful in the design and evaluation of randomized controlled trials that investigate the utility of ultrasound in the treatment of lower back pain.

The purpose of the present study was to examine the ability of continuous 1-MHz ultrasound applied at intensities of 1.5 W/cm² and 2.0 W/cm² for 10 minutes to produce heat in the region of the L4-L5 lumbar zygapophyseal joints. It was hypothesized that (a) 1-MHz ultrasound would produce a significant elevation in temperature in the L4-L5 periarticular region in 10 minutes, and (b) there would be a significant difference in the heating effect between the 2 application intensities used.

METHODS

Subjects

Subjects were 6 healthy males, ages 22 to 38 years (mean, 25.8 years; SD, 6.0 years). Height varied from 170.2 to 185.4 cm (mean, 178.2 cm; SD, 5.7 cm), and mass from 66.7 to 81.6 kg (mean, 76.3 kg; SD, 5.6 kg). The study was explained to all volunteers and each subject signed an informed consent approved by an Institutional Review Board of the Medical University of South Carolina. A review of systems and medical history were obtained and volunteers were excluded from the study if they reported poor health or a current illness (eg, infection, systemic disease), neurological signs or symptoms, a current episode of lower back pain, a history of a bleeding disorder, or if they were taking anticoagulant medication.

Procedures

Subjects were placed prone on an examination table with a pillow under the ankles and the waist for comfort. The position of the lumbar spine was observed to remain in a mild lordosis (Figure 1). The L5-S1 interspinous space was initially identified by adhesive tape was used to create a 10 x 5-cm template for the ultrasound treatment area. The right L4-L5 zygapophyseal joint was estimated to be at the center of the open area inside the tape. A 5-cm diameter ultrasound head was placed in the open area and moved longitudinally in cranial and caudal directions to administer the ultrasound.
palpation during extension of the hips and anterior tilt of the pelvic girdle. The spinous processes of the lumbar vertebrae were palpated and marked with a skin pen.

A C-arm fluoroscopic device (General Electric OEC, Salt Lake City, UT) was moved into place to view the lumbar spine in the sagittal plane, the frontal plane, and at angles to these planes. An anesthesiologist with experience performing lumbar facet joint injections inserted a gas-sterilized 21-gauge copper-constantan type T hypodermic thermocouple (Physitemp Instruments Inc, Clifton, NJ) into the lower back. The thermocouple was inserted through the skin, lateral to the area to receive ultrasound, and the tip was angled medially toward the zygapophyseal joint. The tip of the thermocouple was located adjacent to the posterior L4-L5 zygapophyseal joint. Location was confirmed by radiographic views in multiple planes and agreed upon by the anesthesiologist, an orthopedic surgeon, and a physical therapist. The thermocouple was connected to a calibrated, microcomputer thermocouple thermometer (Model HH71, OMEGA Engineering Inc, Stamford, CT). The lead and the hypodermic thermocouple were then taped to the subject to prevent movement of the thermocouple tip. Subjects were instructed not to move until completion of the experiment.

A 10 × 5-cm area (twice the area of the ultrasound transducer casing)\(^5,7,15,26\) was marked on the right side of the lower back and a template was made using adhesive tape (Figure 1). The L4-L5 zygapophyseal joint was estimated to be near the center of the open area of the template. Ultrasound coupling medium (Aquasonic) at a temperature of 18°C was copiously placed on the skin in the open area within the tape template on the lower back. The temperature in the region of the L4-L5 zygapophyseal joint was then measured for 10 minutes to assure temperature stability. At the end of the 10-minute period, the ultrasound transducer was moved in a linear longitudinal direction inside the template replicating the method for ultrasound application, but with the ultrasound unit turned off. At the end of the 2-minute placebo ultrasound, the ultrasound was turned on and ultrasound was administered over the open area of the template as depicted in Figure 1.

The transducer was pressed firmly against the back until skin deformation was noted, and manually moved in a cephalocaudal longitudinal direction within the open area of the template on the lower back. A metronome was used to allow consistent timing of the movement of the transducer. The edge of the ultrasound transducer was taken to the inner edge of the template at the cephalic and caudal ends of the template, allowing it to cover the longitudinal distance (10-cm open area with a 5-cm displacement of the center of the transducer in either direction) in a single line over 2 seconds, producing a rate of 2- to 3-cm/sec movement for the center of the transducer.\(^5,7,6,9,15,25,26\)

The ultrasound was administered as continuous at 1.5 W/cm\(^2\) and 2.0 W/cm\(^2\) for 10 minutes each, with the order of intensity counterbalanced so that 3 subjects received 1.5 W/cm\(^2\) ultrasound first, while 3 received 2.0 W/cm\(^2\) first. The treatment was timed by a digital stopwatch, while temperature measurements were recorded at 15-second intervals. Additional coupling medium was added if a subject complained of excessive surface heating or if the transducer began to drag over the skin.

At the end of the first 10-minute treatment period the ultrasound unit was turned off and the temperature was allowed to return to baseline. After 10 minutes at the baseline temperature, the 2-minute placebo ultrasound was repeated and then the ultrasound was administered at the other intensity of interest. At the completion of the second procedure, the thermocouple location was confirmed by fluoroscopy and then removed. Subjects reported that pain was not felt during the administration of the ultrasound, although several did report a feeling of pressure in the lower back or buttock while the thermocouple remained in place. No adverse effects were reported from the experiment.

Data Analysis

Three temperature measurements obtained prior to ultrasound application (B1, after thermocouple localization by fluoroscopy; B2, 10 minutes after localization; B3, after 2 minutes of placebo ultrasound) served as baseline reference points for temperature measures obtained during each ultrasound application. The data of primary interest were temperature measures obtained at each 1-minute epoch during two 10-minute courses of ultrasound.

Data collected during the baseline (B1, B2, and B3) and ultrasound conditions were analyzed separately. ANOVA procedures applied to the baseline data failed to identify any significant main effects or an interaction, thereby indicating that temperature prior to ultrasound administration was invariant. To simplify subsequent analyses, B3 served as the primary baseline measure.
TABLE 1. Mean temperature in degrees centigrade and standard deviation, measured at 1-minute intervals from the L4-L5 zygapophyseal joint during baseline, placebo ultrasound (B1-B3), and continuous ultrasound given at 1.5 W/cm² and 2.0 W/cm².

<table>
<thead>
<tr>
<th></th>
<th>1.5 W/cm² Intensity (Mean ± SD)</th>
<th>2.0 W/cm² Intensity (Mean ± SD)</th>
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<tr>
<td></td>
<td>(Mean ± SD)</td>
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<tr>
<td></td>
<td>36.2 ± 0.36</td>
<td>36.2 ± 0.27</td>
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<td></td>
<td>36.2 ± 0.34</td>
<td>36.1 ± 0.26</td>
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<td>36.2 ± 0.44</td>
<td>36.2 ± 0.27</td>
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<tr>
<td>1 min</td>
<td>36.5 ± 0.40</td>
<td>36.5 ± 0.43</td>
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<tr>
<td>2 min</td>
<td>36.8 ± 0.39</td>
<td>36.8 ± 0.46</td>
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<tr>
<td>3 min</td>
<td>37.0 ± 0.31</td>
<td>37.0 ± 0.48</td>
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<tr>
<td>4 min</td>
<td>37.2 ± 0.38</td>
<td>37.4 ± 0.59</td>
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<tr>
<td>5 min</td>
<td>37.4 ± 0.45</td>
<td>37.7 ± 0.65</td>
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<tr>
<td>6 min</td>
<td>37.5 ± 0.40</td>
<td>38.0 ± 0.68</td>
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<tr>
<td>7 min</td>
<td>37.7 ± 0.40</td>
<td>38.4 ± 0.84</td>
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<tr>
<td>8 min</td>
<td>37.9 ± 0.46</td>
<td>38.7 ± 0.80</td>
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<tr>
<td>9 min</td>
<td>38.0 ± 0.49</td>
<td>39.0 ± 0.89</td>
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<tr>
<td>10 min</td>
<td>38.1 ± 0.60</td>
<td>39.3 ± 0.86</td>
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The analysis of interest was a 2 × 11 (ultrasound intensity by 1 baseline and 10 temperature measures during ultrasound administration) repeated-measures ANOVA with orthogonal components for trend. Subsequently, a series of 10 post hoc Bonferroni-corrected paired-samples t tests were performed to identify time points at which the temperature was significantly higher than baseline for each ultrasound intensity. In addition, a series of 10 t tests were used to identify time points at which mean differences between the 2 ultrasound applications achieved significance. The per-comparison Type I error rate was less than or equal to 0.01. All comparisons were 1 tailed.

RESULTS

The t tests comparing baseline to corresponding ultrasound mean temperatures indicated that all temperature measures obtained during ultrasound differed from their corresponding baseline (P ≤ 0.01). The administration of 1 or more minutes of ultrasound, of either intensity, produced an increase in temperature that differed significantly from baseline (Table).

Figure 2 depicts the mean temperature at the L4-L5 zygapophyseal joint obtained at 1-minute intervals during the 1.5-W/cm² and 2.0-W/cm² ultrasound applications. The figure indicates that, while both ultrasound intensities resulted in a largely linear increase in temperature over time, the 2.0-W/cm² ultrasound application produced a more rapid increase with consistently higher temperatures. Because the figure suggests the presence of an apparent ordinal interaction, both the intensity main effect and interaction were interpreted. The ANOVA results yielded both a significant intensity main effect (F₁,₅ = 13.9, P < 0.05), and intensity-by-time interaction (F₁₀,₅₀ = 10.1, P < 0.001), with the latter possessing a significant linear trend component (F₁,₅ = 13.4, P < 0.05). The linear trend component for the interaction confirms a faster rate of temperature increase with the 2.0-W/cm² ultrasound. Post hoc analyses indicated that significant mean temperature differences between ultrasound intensity emerged at the 6-minute time point and persisted over the remaining time points P ≤ 0.01. Thus, the 2.0-W/cm² ultrasound application resulted in a higher overall temperature and a more rapid increase in temperature that began producing significant temperature differences between intensities at 6 minutes after the commencement of ultrasound administration.

DISCUSSION

The present study reports the heating effects of therapeutic ultrasound administered in the region of the lumbar zygapophyseal joints. While it is reasonable to suspect that the intervening muscle may heat as well, the focus of this project was to deter-
-mine the characteristics of the temperature change in the region of the L4-L5 zygapophyseal joint in response to ultrasound administered at 1.5 W/cm² and 2.0 W/cm². While the actual therapeutic benefit and mechanisms concerning the use of ultrasound for treating many musculoskeletal conditions have yet to be established,2,35 a factor that has been implicated as beneficial is an elevation of the temperature in the tissue being treated.1,5,6,8-10,13,14,16,17,23,26,28,33,38

In the present study, a significant interaction between length of treatment and intensity was found. The higher intensity ultrasound produced an elevation in temperature at a more rapid rate than the lower intensity, which agrees with studies using ultrasound to heat muscle7 and tendon.5 It was found that 10 minutes of ultrasound given at 1.5 W/cm² applied to an area twice the size of the transducer, produced a mean temperature increase of 1.9°C, for a mean terminal temperature of 38.1°C, in the region of the L4-L5 zygapophyseal joint. The rate of mean temperature increase during the administration of the 1.5 W/cm² ultrasound was 0.19°C/min. Increasing the intensity of the ultrasound to 2.0 W/cm² produced a mean temperature at 10 minutes of 39.3°C with a mean temperature increase of 3.1°C (0.31°C/min).

Comparing the results of the present study to other studies that have examined the thermal effects of continuous ultrasound in other body regions may be problematic for several reasons. It is known that different 3-MHz ultrasound devices produce varying rates of heating in the triceps surae.16,26 While there are differences in the devices used in the present study and other published works, several studies have examined the thermal effects of continuous 1-MHz ultrasound on the triceps surae using parameters similar to the present study, except for the BNR. One of these studies reported a BNR of 1.8:1,7 the other10 did not report the BNR. Draper et al7 found a mean rate for temperature increase of 0.33°C/min with an intensity of 1.5 W/cm². The mean temperature recorded at 10 minutes reflected a slightly greater than 3°C change. In an earlier study by Draper et al,10 it was found that 1-MHz ultrasound with an intensity of 1.5 W/cm² heated the triceps surae to a mean temperature of 40.3°C in 10 minutes (mean rate of increase, 0.48°C/min). Merrick et al26 demonstrated a 0.3°C/min temperature increase over 7 minutes using 1-MHz continuous ultrasound at 1.5 W/cm², with a slightly faster rate for transducer movement (3-4 cm/sec), but an area of similar size being treated. Draper et al1 reported a 0.38°C/min rate of temperature rise in the triceps surae using 1-MHz ultrasound at 2.0 W/cm². All of these studies demonstrated a more rapid rate of heating in the triceps surae area than was found in the present study for the lumbar zygapophyseal joint area, at either intensity.

Among the factors that could influence the thermal effects is the depth used for temperature measurement. The actual depth for the temperature measurement at the lumbar zygapophyseal joints in the present study was not measured and is believed to vary to some degree between subjects. Finding no interaction between intensity and the depth of temperature measurements, Draper et al10 reported a nonsignificant mean temperature difference measured at 2.5- and 5-cm depths in the triceps surae using parameters of ultrasound administration similar to the present study. Merrick et al26 took temperature measurements at a 3-cm depth. The comparison in the terminal temperatures and heating rates between the triceps surae and the lumbar periarticular region suggests that the region of the lumbar zygapophyseal joints heats at a lower rate than the triceps surae when 1.5-W/cm² ultrasound is used. It appears that a 2.0-W/cm² intensity heats the lumbar periarticular region at a lower rate than the triceps surae as well, but the difference is not as great as with the 1.5-W/cm² intensity. A difference in the BNR of the ultrasound devices used for these studies may contribute to the observed differences. Future studies are needed to discern if there are truly different heating characteristics between body regions or if differences are related to the device used.

In the present study, 3 of the subjects receiving 2.0-W/cm² ultrasound demonstrated a change in temperature to 40°C at the 10-minute mark. Merrick et al26 report that subjects requested termination of treatment due to discomfort when the intramuscular temperature in the region of the triceps surae reached 40.5°C to 41.5°C. In the present study, none of the subjects complained of excessive heating or uncomfortable sensations at either intensity, thus, the intensity did not have to be adjusted or treatment terminated to accommodate for comfort of the subjects.

The temperature elevation observed in the present study at 10 minutes of treatment using either intensity was at a level thought to be sufficient to produce the theoretical therapeutic effects proposed with an elevation in temperature.20,23,34 When using the methods and equipment described in this study, it will take 10 minutes to elevate the temperature in the region of the L4-L5 zygapophyseal joint 3°C using a 2.0-W/cm² intensity. In the present study, the presence of a significant linear trend in temperature change suggests that extending the treatment time would likely lead to additional temperature elevation. In their analysis of the literature, the majority of which consisted of in vitro studies, Tillman and Cummings38 discuss the potential for temperature elevation in the range found with this study to produce several effects on dense connective tissue.
These include the potential for an alteration in the stress-strain characteristics of the tissue. While the dense connective tissue may become more ductile, it may also become weaker when heated. This has yet to be confirmed with clinical studies.

The present study has several limitations. First, the clinical utility of ultrasound for modifying signs or symptoms with lower back pain was not investigated. However, the study does establish some parameters that should be considered when designing research to elucidate the clinical utility of ultrasound related to thermal changes. Future studies will need to investigate the relationship between the ultrasound “dosage” and the clinical outcome with musculoskeletal pain or soft tissue lesions. Second, a small sample size (n = 6) was tested and the subjects were physically fit males, which reduces the generalization of the results. The actual thermal changes that would occur using the described methods in a population of individuals with different physical characteristics may differ from the results of the present study. Of note, it was observed that the subject who demonstrated the least elevation in temperature during the study was the smallest subject, but the study design does not allow any inferences to be made concerning body size or composition in relation to heating. Even with the small sample size, statistical significance for temperature change was found. Third, the area for temperature measurement was specific to the region of the zygapophysial joint. Temperature changes in areas other than the posterior aspect of the zygapophysial joint were not measured. Finally, and as discussed earlier, based on the demonstrated inconsistency in heating across various 3-MHz devices, it is not possible to conclude that all 1-MHz ultrasound units will produce the same thermal characteristics, even when the same intensities are used.

CONCLUSION

The present study demonstrated that continuous 1-MHz ultrasound used at intensities of either 1.5 W/cm² or 2.0 W/cm² can heat lumbar periartricular tissue in the region of the L4-L5 zygapophysial joint when the transducer is moved linearly over an area twice the size of the transducer, and at a 2- to 3-cm/sec rate. There was a significant interaction between the length of treatment and the intensity used, with ultrasound given at 2.0-W/cm² heating the tissues more rapidly than when given at 1.5 W/cm². The rate of heating of the periartricular area with ultrasound at either intensity appears to be lower than the rate of heating in the triceps surae. Overheating or discomfort with treatment did not occur at either intensity within the 10-minute treatment.

REFERENCES


