A Comparison of Temperature Rise in Human Calf Muscles following Applications of Underwater and Topical Gel Ultrasound

David O. Draper, EdD, ATC[1]
Scott Sunderland, MS, ATC[2]
Donald T. Kirkendall, PhD[3]
Mark Ricard, PhD[4]

Ultrasound is one of the most widely used therapeutic modalities for treating soft tissue injuries. In 1987, 4 million ultrasound treatments were performed in Canada (17). Many of its uses have been documented, including wound healing (4), reabsorption of calcium deposits (2), increasing tendon extensibility (6), pain relief (9, 18), and treatment of plantar warts (1, 8, 13, 16). Ultrasound treatment of sports injuries is on the rise. It is the treatment of choice when tissue temperature rise is indicated for a variety of soft tissue dysfunctions (11, 12).

Ultrasound is a sound wave generator that operates above the audible threshold of humans. Therapeutic ultrasound is administered at a frequency in the range of 800,000 to 3 million Hz. These sound waves cause molecular vibration and collision, and the increase in molecular activity results in heat (7). The therapeutic benefits of ultrasound are derived from the transfer of mechanical to thermal energy. The therapeutic benefits of ultrasound are classified as thermal or nonthermal. The majority of ultrasound treatments are administered to obtain thermal benefits. Thermal effects of

For ultrasound to be effective, a conducting medium must be placed between the soundhead and the skin. Little research has been performed to test whether or not these mediums actually work. The purpose of this study was to compare the effect of tap water immersion and ultrasound gel conducting mediums on tissue temperature rise in the human leg. A 23-gauge hypodermic needle microprobe was inserted 3 cm deep into the medial portion of the gastrocnemius muscle of 20 subjects. Each subject participated in two random order treatments using tap water immersion and topical gel conducting mediums. Each treatment consisted of continuous ultrasound delivered topically at 1.5 W/cm² for 10 minutes. During both treatments, the soundhead was moved at a speed of 4 cm per second, and the temperature was recorded every 30 seconds. A significant difference was found between the two treatment methods [$t(19) = 9.18$, $p < .001$]. The topical gel increased tissue temperature 4.8 °C, whereas the underwater treatment increased tissue temperature only 2.1 °C. Therefore, at a tissue depth of 3 cm, ultrasound gel is a better conducting medium than water. Also, the authors discovered that it took nearly 8 minutes for the temperature to reach therapeutic levels during the gel technique. These findings should be of clinical significance to clinicians who regularly use ultrasound.

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[1] Associate professor, associate coordinator, Athletic Training, Department of Physical Education, 221 Richards Building, Brigham Young University, Provo, UT 84602
[2] Staff athletic trainer, Galesburg Orthopaedics; head athletic trainer, Knox College, Galesburg, IL
[3] Associate professor, Exercise Physiology, Illinois State University, Normal, IL
[4] Assistant professor, Biomechanics, Illinois State University, Normal, IL

ultrasound delivered in a continuous mode include reduction of pain (18), increased blood flow (10), reduction of muscle spasm, decreased joint stiffness, increased collagen tissue extensibility, and tissue healing (4).

Ultrasound waves are not transmitted through the air; therefore, a conducting medium placed between the applicator head and the skin is required. Prentice defined a coupling medium as a substance used to transfer sound waves (12). Williams characterized the function of a coupling medium as a substance that excludes air from the region between the transducer head and the patient's skin, allowing the ultrasound wave to pass into the tissue at its highest intensity (20). Therefore, a coupling medium must possess good transmissibility qualities that enable the applicator head to glide against smooth or uneven skin surfaces.

Clinically, a variety of coupling mediums are being used, including ultrasound gel, water, mineral oil, distilled or degassed water, and glycerine. Of these, ultrasound gel applied topically and immersion in tap water appear to be the most common.

An ultrasound treatment is only as effective as the method or medium used to deliver it (15). For this reason, we developed this *in vivo* study to determine whether ultrasound gel or water was the best conducting medium for elevating tissue temperature.

METHODS

Subjects

Twenty male students volunteered to participate as subjects. Their mean age was 23 years (range = 19–31). The treatment area (calf muscles) was free from localized infection, ecchymosis, or swelling, and from injury within the last 6 months. Care was taken to select subjects who were free of excessive adipose tissue in the lower leg. The experiment was preapproved by the university's institutional review board. Subjects were instructed about the procedures and risks. Each subject viewed a videotaped pilot study that illustrated what would be expected. Each participant then signed an informed consent form.

Subjects were placed on an antibiotic therapy program on the day of participation to reduce the risk of infection. One 500-mg dose of cephalexin hydrochloride (Keftab) was taken 6 hours before the experiment, and three more doses were administered afterwards, one dose each at 6-hour intervals.

Instruments

The ultrasound unit was a Sonicator 706 (Mettler Electronics, Anaheim, CA). The generator operates at a frequency of 1.0 MHz = ±5%.

The transducer head is 5 cm in diameter and houses a lead zirconate titanate crystal. The unit was less than 1-year old and was calibrated via an ultrasound power meter prior to the study.

The needle thermistor (Phystek MT-23/5, Physitemp Instruments, Clifton, NJ) was connected to a digital monitor (Bailey Instruments BAT-12, Physitemp Instruments, Clifton, NJ), which displayed the temperature in °C.

The two coupling mediums used in this study were tap water and Aquasonic 100 Ultrasound Transmission Gel (Parker Laboratories, Orange, NJ). The tap water (37 °C) was run into a plastic container. The

> *The sound head was moved in a longitudinal overlapping manner at a speed of approximately 4 cm per second.*

ultrasound gel was warmed over a hotplate to 37 °C. Each medium was monitored via a mercury thermometer to ensure a constant 37 °C temperature.

Procedures

Each subject underwent both treatments on the same day to minimize the variability associated with reinsertion of the thermistor. The order of treatment was randomly assigned. A 10-cm-diameter area on the center of the belly of the right medial gastrocnemius of each subject served as the treatment target. This area was shaved and washed with soap and water, cleansed with a beta-

dine scrub, then swabbed with 70% isopropyl alcohol. The skin was locally anesthetized by a subcutaneous injection of .5 cc of 1% lidocaine (Xylocaine).

The thermistor was sterilized the evening before each day of data collection by immersing it in glutaraldehyde solution (Cidex) for 8 hours. This procedure was repeated for 15 minutes between each subject. The thermistor was inserted into the belly of the right medial gastrocnemius muscle while the subject was lying prone. The distance from the posterior calf through the sagittal plane to the tip of the needle was 3 cm. This represented the 3-cm tissue thickness that the ultrasonic waves needed to penetrate in order to cause the thermistor needle to react to any change in temperature (Figure 1). The thermistor was then connected to the monitor, and the temperature was allowed to plateau (approximate time = 5 minutes). At this time, a baseline reading was recorded. An ice pack was applied to the skin to lower the temperature to the baseline level between treatments. For this reason, the order of treatments was counterbalanced by randomly selecting 10 subjects to receive the water immersion treatment first and the other 10 to receive the topical gel treatment first.
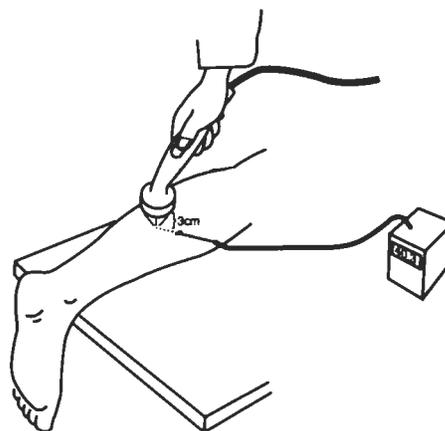

FIGURE 1. *Tissue temperature was measured by inserting a needle thermistor 3 cm below the ultrasound treatment area.*

During the water immersion treatment, the subject sat in a chair and slipped his leg in the water. A jig for the soundhead was constructed to ensure that the distance between the soundhead and the skin was 1 cm for all subjects (Figure 2). As the surface of the jig glided on the skin during the treatment, it served to sweep away air bubbles that formed between the skin and the soundhead. The ultrasound head was immersed in the water, and the unit was turned on and adjusted to 1.5 W/cm² at a continuous setting. The sound head was moved in a longitudinal overlapping manner at a speed of approximately 4 cm per second. These strokes were twice the size of the soundhead in an area 10 cm in diameter. The temperature was recorded to the nearest 0.1 °C every 30 seconds for 10 minutes or until there was no temperature increase on three consecutive readings.

For the topical gel treatment, 15 ml of 37 °C ultrasound gel was applied to the treatment area. This treatment followed the same parameters as the water treatment with respect to ultrasound intensity and time as well as speed and movement stroke of the soundhead. The only difference was that the soundhead applicator came into direct contact with the skin. Care was taken to

ensure a tight bond between the sound-head, gel, and skin so that air bubbles would not get trapped and cause attenuation of the beam.

The thermistor was removed, and the area was cleansed with betadine solution. Ice packs were applied to the area for 10 minutes to help reduce the risk of hematoma. After the ice treatment, a bandage was applied to the injection site, and the subject was dismissed. No complications or infections resulted from this study.

An additional, single subject was used to test the effect of soundhead movement on temperature changes. The above methods for both the underwater and topical gel techniques were followed, except that the ultrasound unit was not turned on. There was no change in temperature when

The topical gel technique increased the temperature of the muscle 13.9%.

the unit was off, therefore, the light massaging of the soundhead on the skin was determined to not effect the outcome of this study.

Statistical Analysis

A dependent t-test was used to test for significant differences in maximal tissue temperature rise between the two ultrasound treatment methods (underwater and topical gel). Alpha was set at 0.05.

RESULTS

The mean baseline temperature for each treatment was 35.5 °C (±.5 °C). Tissue temperature for the underwater treatment peaked at a mean of 37.6 °C (range of standard deviations was .93–1.24 °C). Peak

tissue temperature for the topical gel ultrasound treatment was 40.3 °C (range of standard deviations was .85–1.74 °C). When compared with the water technique, ultrasound applied with the gel technique caused a significantly greater increase in peak temperature [$t(19) = 9.18$, $p < .001$]. Overall, the topical gel technique increased the temperature of the muscle 13.9%, whereas the tapwater immersion technique resulted in just under a 6% increase in muscle temperature (Figure 3).

Regarding peak temperature, only one subject reached a plateau during the 10-minute gel treatment. All of the ultrasound treatments plateaued when performed underwater ($\bar{x}$ time = 8 minutes). Also, it took an average of 7.5 to 8 minutes for the gel treatment to reach a therapeutic level of 40 °C (Figure 4).

DISCUSSION

Research findings regarding the effects of several ultrasound conducting mediums have varied. Reid and Cummings (14) believe that ultrasound gel is the best conducting medium. They found that ultrasound only transmitted about 59.38% of its power through distilled water, whereas 72.60% of its power was transmitted through ultrasonic gel (14). Warren et al (19) also studied the relative transmissitivity of ultrasound through various coupling mediums. In contrast, they

FIGURE 2. During the underwater treatment, a jig was attached to the soundhead in order to maintain a constant 1-cm distance between the soundhead and the skin.
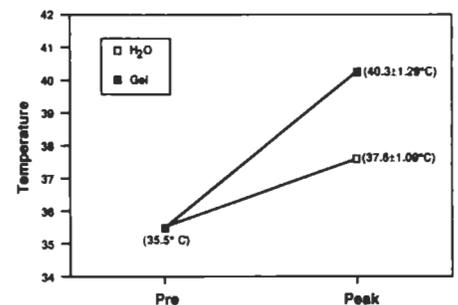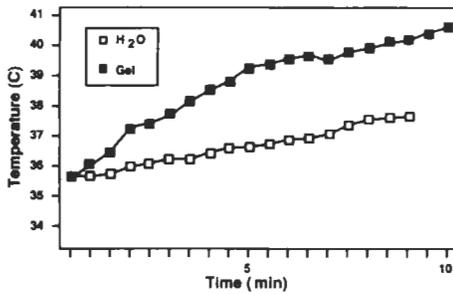
FIGURE 3. Pre and peak muscle temperature by ultrasound treatment method. When compared to the water, the gel method produced a significant increase in muscle tissue temperature.

FIGURE 4. Muscle temperature as a function of time by ultrasound treatment method.

found no significant difference in transmissiveness of ultrasound gel and water and believe that a coupling medium should be selected based solely on cost and convenience.

One possible reason for these varied results might be the incompatible methods of data collection. In these two examples (14, 19), data were not collected under the same *in vivo* conditions in which ultrasound treatments were given (3). Several *in vitro* studies have been performed on ultrasound conducting mediums. These artificial lab experiments often measure transmissitivity on an oscilloscope. Other ultrasound research has been performed on animals, including mice, rabbits, dogs, and pigs (11).

There has been a lack of *in vivo* research on the use of ultrasound on humans (3). *In vitro* studies can produce artificial results because they depend on the acoustic impedance of the coupling medium and whether the medium produces a sufficient resonant length. Acoustic impedance is defined as the ability of the sound wave to travel in a substance, and resonant length is defined as the distance a sound wave travels. Williams stated that different lengths have different acoustic velocities, and these may vary from that of human tissue (20). Reid and Cummings concurred with these limitations of *in vitro* study and stated that future study of ultrasound conducting mediums needed to be performed *in vivo* on humans (14). To our knowledge, no

human *in vivo* studies on ultrasound conducting mediums have been performed in the past 20 years since Lehman's studies in the 1960s (10). Since ultrasound crystals and generators have improved in the past two decades, we felt that it was important to revisit *in vivo* ultrasound studies on humans.

The results of this study are important for anyone who uses therapeutic ultrasound to increase the temperature of tissues up to 3 cm deep. Based on the results of Forest and Rosen's studies (5), ultrasound must heat tissues to at least 40 °C in order for them to receive therapeutic effects. Our results confirmed that topical application of ultrasound gel is effective for obtaining this

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Ultrasound must heat tissues to at least 40 °C in order for them to receive therapeutic effects.

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temperature, whereas the tap water immersion technique is not effective.

The failure of the underwater technique to significantly raise tissue temperature might be due to the absorption of the sound in the water. During the gel technique, the soundhead comes into direct contact with the skin. With the water technique, a distance of 1 cm between the soundhead and the skin is recommended. Possibly this 1-cm distance impedes the complete penetration of the beam into the tissues. We base this premise on a previous pilot study involving three subjects. We discovered that the farther the soundhead was placed from the tissues during the water immersion technique, the less the tissue temperature rise (3).

Another explanation for these results might be unforeseen air bubbles getting trapped between the skin and the soundhead. For this reason, many clinicians use distilled or degassed water during the immersion technique. Further tests need to be performed on degassed water before it can be concluded that the gel technique is always superior to the immersion technique.

Typically, the tap water immersion technique is used on bony prominences or over uneven areas of the skin. If the tissues are superficial, this technique may work, but it has not yet been scientifically tested. At present, the results of this study strongly suggest that therapeutic ultrasound using the tap water immersion technique is ineffective in raising soft tissue temperature. Therefore, if the goal is tissue temperature rise in deep tissues, the method of application should be topical ultrasound gel.

These results also point to the importance of length of ultrasound treatments. A therapist must take into account the size of the treatment area before determining the treatment time. We have observed many ultrasound treatments and have found that most last only 5 minutes, regardless of the size of the area being treated. Reid and Cummings' (14) suggestion that treatment time should be 5 minutes for an area two to three times the size of the soundhead was not supported by our findings. According to our data, the tissues do not reach the 40 °C therapeutic temperature level until after 7.5 to 8 minutes of ultrasound therapy using Aquasonic 100 transmission gel. Based upon these results, ultrasound treatments should last from 7 to 8 minutes when treating an area two to three times the size of the soundhead.   JOSPT

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