

Effects of 3.3-MHz Ultrasound on Caudal Thigh Muscle Temperature in Dogs

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Objective—To examine the tissue-temperature changes that occur at various depths during 3.3-MHz ultrasound (US) treatments of the caudal thigh muscles in dogs.

Study Design—A prospective, randomized, experimental study.

Animals—Ten mixed-breed research dogs.

Methods—Two US treatments, one at an intensity of 1.0 W/cm² and one at 1.5 W/cm², were administered to the caudal thigh region of 10 adult male and female hound-type dogs weighing 20.5 to 25.0 kg. Needle thermistors were inserted in the caudal thigh muscles below the skin surface at depths of 1.0, 2.0, and 3.0 cm, directly under the US treatment area. Both intensities of US treatment were performed on each dog over a 10-cm² area for 10 minutes using a sound head with an effective radiating area of 5 cm². Treatments were administered in random order. Tissue temperature was measured before, during, and after US treatment until tissue temperature returned to baseline.

Results—At the completion of the 10-minute US treatment, the temperature rise at an intensity of 1.0 W/cm² was 3.0°C at the 1.0-cm depth, 2.3°C at 2.0-cm depth, and 1.6°C at 3.0-cm depth. At an intensity of 1.5 W/cm², temperatures rose 4.6°C at the 1.0-cm depth, 3.6°C at 2.0-cm depth, and 2.4°C at 3.0-cm depth. Tissue temperatures returned to baseline within 10 minutes or sooner after treatment in all dogs.

Conclusions—This study demonstrates that significant heating occurs in the superficial thigh muscle of dogs during 3.3-MHz US.

Clinical Relevance—3.3-MHz US can be used to increase superficial tissue temperature in dogs, although the amount of time that tissue temperature remains elevated is relatively short.

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THERAPEUTIC ULTRASOUND (US) has been used to treat a variety of conditions. The effects of US can be divided into thermal and nonthermal, or biologic effects. The thermal effects of US on human tissues are well documented and include decreased pain, reduced muscle spasm, and increased extensibility of collagen, allowing tissues to be stretched more effectively.¹⁻¹² Tissue temperature should be raised at least 3° to 4°C above normal to obtain the optimal

increases in tissue extensibility associated with improving flexibility.^{8-9,13} The treatment parameters needed to achieve this degree of temperature elevation in dogs are unknown. Nonthermal or biologic effects of US include acceleration of the inflammatory phase with a quicker entry into the proliferative phase of repair,^{14,15} stimulation of fibroblast proliferation,¹⁶⁻¹⁸ and decreased pain.^{4,5} Other biologic effects include promotion of stronger and more elastic scar tissue due

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to an improvement in collagen organization with collagen fibers arranged along more normal lines of tension,^{14,15,19} and changes in membrane permeability that may speed the healing process.^{14,15}

A variety of US frequencies have been studied in humans, with the most common being 1.0 MHz and 3.3 MHz. One-megahertz US has its greatest effects on tissue depths of 2.5 to 5.0 cm.^{1,2,6,10,13} US of 3.3 MHz has its greatest effects from 1.0 to 2.5 cm of tissue depth.² Other frequencies have also been studied, such as 45 kHz, which produces little heating of tissue.⁶ One recent study examined the effects of 1.0-MHz US on elevation of tissue temperature at depths of 5.0 cm and 10.0 cm in the caudal thigh muscles of dogs.¹⁰ Using intensities varying from 0.5 to 2.0 W/cm², and treatment times of 10 minutes, temperature increases were less than 0.6°C at the 10-cm depth for all treatments. At a depth of 5 cm, temperature increased 1.0°C, 2.0°C, and 3.5°C at intensities of 1.0 W/cm², 1.5 W/cm², and 2.0 W/cm², respectively. Because many tissues in the dog are more superficial than 5.0 cm, we examined the thermal effects of 3.3-MHz US. The amount of tissue-temperature increase is directly related to the intensity of US.^{1-3,10} Intensities of 1.0 W/cm² and 1.5 W/cm² were chosen for this study because they have previously been shown to elevate tissue temperatures to therapeutic ranges without causing discomfort in humans.^{1-3,13}

The purpose of this study was to evaluate the effects of 3.3-MHz US on tissue heating at 1.0-, 2.0-, and 3.0-cm depths, using 1.0- and 1.5-W/cm² intensities. The hypothesis was that significant tissue-temperature increases could be obtained during US treatment, and that the 1.5-W/cm² intensity would produce significantly greater heating than the 1.0-W/cm² US treatment.

MATERIALS AND METHODS

Ten normal adult hound-type dogs weighing 20.5 to 25.0 kg were used in this study. All procedures were approved by the University of Tennessee Animal Care and Use Committee. Hair over the caudal thigh muscles was clipped, because hair coat has previously been shown to impede the successful transmission of US.¹⁰ Dogs were sedated with tiletamine HCl and zolazepam (Telazol, Fort Dodge Laboratories Inc, Fort Dodge, IA) (0.2 mg/kg of body weight, intramuscularly), and butorphanol tartrate (Torbugesic, Fort Dodge Laboratories Inc) (0.2 mg/kg of body weight, intramuscularly). The sedated dogs were placed in lateral recumbency and covered with a blanket to help maintain normal core temperature

during sedation. The skin was prepped with alternating scrubs of 2% chlorhexidine acetate and 70% isopropyl alcohol. Using a specially designed jig (Fig 1), needle thermistors (23-gauge, 5.0 cm in length) (MT 23/5 Physitemp Instruments, Clifton, NJ) were inserted into the caudal thigh muscles at depths of 1.0, 2.0, and 3.0 cm directly below the surface of the treatment area. Thermistor needles were connected to a digital monitor (Dianachart Inc, Rockaway, NJ) interfaced with a microcomputer that recorded tissue temperature at 1-second intervals for the duration of the study.

A 10.0-cm² template was used to outline the US treatment area. US was administered using standard US transmission gel (Aquasonic 100, Parker Laboratories, Orange, NJ) for 10 minutes using a sound head with an effective radiating area of 5.0 cm² (Fig 2). The US unit (Sonicator 730, Mettler Electronics Corporation, Anaheim, CA) was calibrated immediately before initiation of the study. Dogs were randomly assigned to receive either the 1.0-W/cm² or the 1.5-W/cm² intensity first. Three minutes of baseline tissue temperature was recorded after insertion of thermistor needles, followed by the 10-minute US treatment. Data were collected for an additional 15 minutes to study the rate of cooling. After an additional 30 minutes to allow tissue

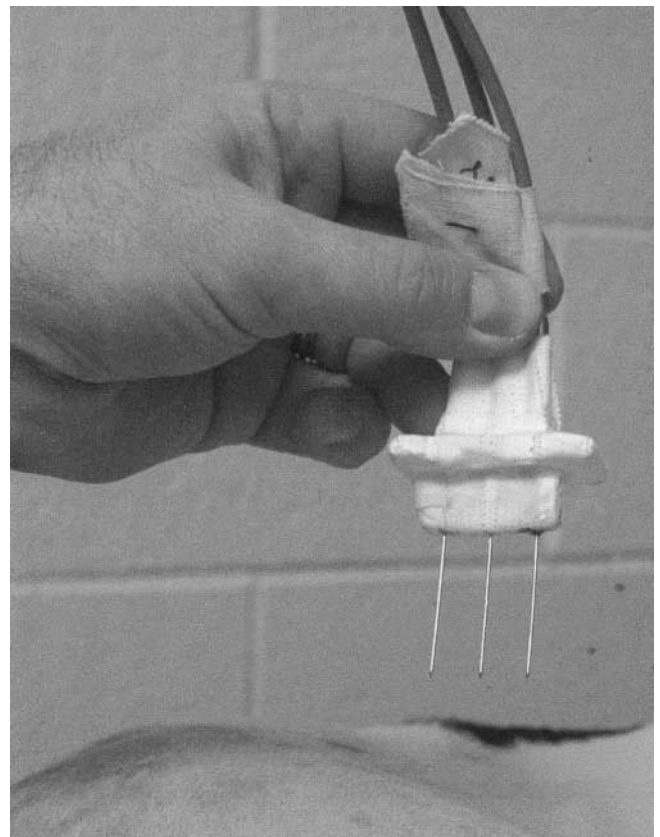


Fig 1. Needle thermistors spaced 1.0 cm apart for insertion into tissue.

temperature to stabilize and return to baseline values, the experiment was repeated at the alternate US intensity.

Statistical Analysis

Baseline tissue temperature between trials was compared using a paired *t* test to assess if any differences occurred as a result of length of sedation. Using a computerized statistical program,²⁰ mean temperatures were calculated at 30-second intervals for each treatment and at each depth. Data were evaluated for normal distribution before statistical testing. A mixed-model ANOVA with repeated measures was used to test for differences in mean temperatures obtained at each depth (3 levels), and each intensity (2 levels) of US treatment. Differences between individual means were established with LSD mean separation. Results were considered significant at $P < .05$.

RESULTS

Changes in tissue temperature during the 3 minutes before US treatment, 10 minutes of US treatment, and 15 minutes after US treatment at 1.0-W/cm² and 1.5-W/cm² intensities are displayed in Figs 3 and 4. Baseline tissue temperature was not significantly different ($P > .05$) between trials at any of the 3 depths, eliminating sedation as a factor affecting temperature during the time frame of this study. The difference in temperature from baseline to the end of the 10-minute US treatment was significant at all depths for both intensities ($P < .0001$). Tissue-temperature increases were significantly greater ($P < .01$) using 1.5-W/cm² US as compared with 1.0-W/cm² US at all tissue depths. Furthermore, the rate of heating was greater

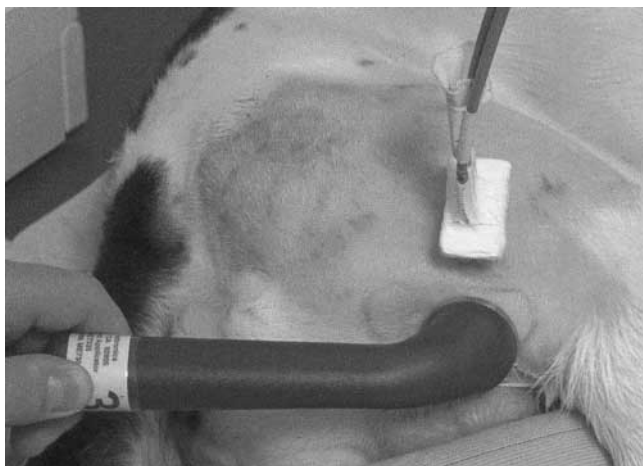


Fig 2. Needle thermistors placed in tissue with US treatment being applied to the outlined area.

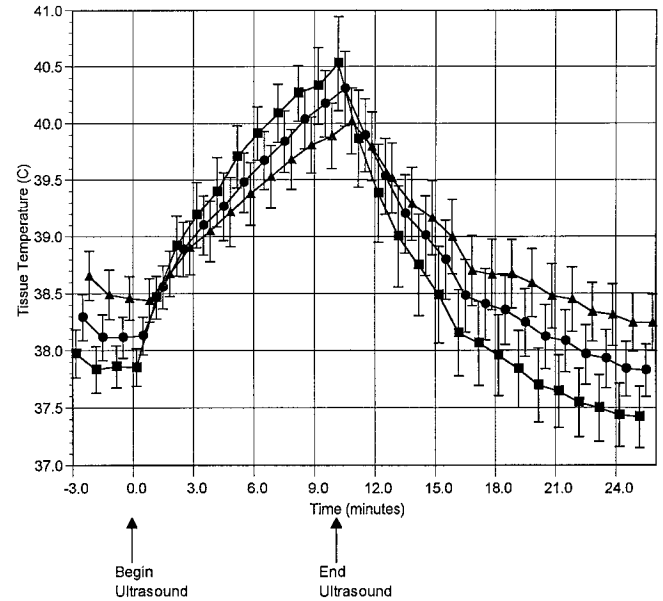


Fig 3. Baseline, US treatment, and posttreatment tissue temperatures for 1.0-W/cm², 3.3-MHz US at 1.0-, 2.0-, and 3.0-cm tissue depths. Values are means (SEM). (■), 1 cm; (●), 2 cm; (▲), 3 cm.

using 1.5-W/cm² as compared with 1.0-W/cm² US (time \times intensity interaction; $P < .0001$).

At the completion of the 10-minute 1.0-W/cm² US treatment, the temperature rise was 3.0°C at the 1.0-cm depth, 2.3°C at 2.0-cm depth, and 1.6°C at 3.0-cm depth. At an intensity of 1.5 W/cm², temper-

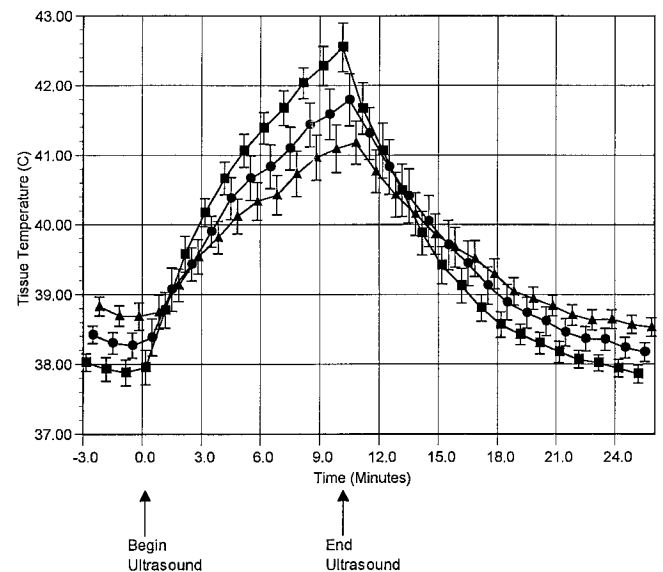


Fig 4. Baseline, US treatment, and posttreatment tissue temperatures for 1.5-W/cm², 3.3-MHz US at 1.0-, 2.0-, and 3.0-cm tissue depths. Values are means (SEM). (■), 1 cm; (●), 2 cm; (▲), 3 cm.

atures rose 4.6°C at the 1.0-cm depth, 3.6°C at 2.0-cm depth, and 2.4°C at 3.0-cm depth. The tissue-temperature changes over time were significantly different among the 3 tissue depths (time \times depth interaction; $P < .05$), with greater temperature increases occurring in the more superficial tissues.

At an US intensity of 1.5 W/cm², it took approximately 5.5 minutes at a tissue depth of 1.0 cm and 8.5 minutes at a depth of 2.0 cm to raise tissue temperature 3.0°C above baseline (Figs 3 and 4). At a depth of 3.0 cm, maximal temperature increase was only 2.4°C after 10 minutes. At an intensity of 1.0 W/cm², a 3.0°C temperature increase was obtained only at the 1.0-cm depth only after 10 minutes of US.

The length of time after the 10-minute US that tissue temperature was 3.0°C greater than baseline was 2 minutes for the 1.5-W/cm² intensity at the 1.0-cm depth, 1 minute for the 1.5-W/cm² intensity at the 2.0-cm depth, and 0.25 minutes for the 1.0-W/cm² intensity at the 1.0-cm depth (Figs 3 and 4).

DISCUSSION

Baseline tissue temperatures were greatest at the 3.0-cm depth, followed by 2.0-cm and 1.0-cm depths. This was expected because the deeper tissues are closer to the body's core. Despite the lowest baseline temperature, the greatest increases in heating occurred at the 1.0-cm depth, followed by depths of 2.0 and 3.0 cm, which is in agreement with a previous study using 3.3-MHz US in humans.²

Although the specific tissue-temperature increase needed to improve tissue extensibility has not been determined in dogs, research suggests that a 3°C to 4°C increase in tissue temperature is effective in improving flexibility in both animals and humans.^{8,9,13} The use of 3.3-MHz US in this study caused greater than 3.0°C tissue-temperature elevation in 3 of the 6 US trials (1.0 W/cm², 1.0-cm depth; 1.5 W/cm², 1.0-cm depth; and 1.5 W/cm², 2.0-cm depth). Increasing either the treatment time or the US intensity may have achieved an increase in tissue temperature to therapeutic levels in these conditions, although increasing intensity above 1.5 W/cm² may predispose the tissue to a greater chance for thermal damage. The difficulty in increasing tissue temperature at 3.0 cm suggests that 3.3-MHz US may be limited to increasing tissue temperature from the surface to 2.0 cm in depth. In comparing intensities, the 1.5-W/cm² inten-

sity elevated tissue temperature significantly higher than the 1.0-W/cm² intensity at all depths.

The length of time after US treatment that tissue temperature remained 3.0°C greater than baseline was relatively short. When combining the amount of time that tissue temperature was 3.0°C greater than baseline, both during and after US, it was 6.5 minutes for the 1.5-W/cm² intensity at the 1.0-cm depth, 2.5 minutes for the 1.5-W/cm² intensity at the 2.0-cm depth, and 0.25 minutes for the 1.0-W/cm² intensity at the 1.0-cm depth. Because the temperature increase was short in all conditions studied, this suggests that for optimal gains in range of motion, stretching should be applied during the treatment, if possible, and immediately after. Placing the tissues on a slight stretch during at least the last minute or two of the US treatment and increasing the stretch as the tissues elongate may be most beneficial.

There have been relatively few in vivo studies measuring tissue temperature change in response to US. Draper et al¹ demonstrated tissue temperature increases in human calf muscles of 4.8°C at a depth of 3.0 cm using 1.0-MHz US at an intensity of 1.5 W/cm². In a similar study, Ashton et al¹² found a mean increase of 3.2°C at a depth of 3.0 cm using 1.0-MHz US at an intensity of 1.5 W/cm², also on human calf muscles. Steiss and Adams¹⁰ showed tissue-temperature increases of 2.0°C (1.5 W/cm²) and 3.5°C (2.0 W/cm²) in the caudal thigh muscles of dogs at a depth of 5.0 cm using 1.0-MHz US. These studies, coupled with our findings, suggest that 3.3-MHz US may be best suited to heating tissues from the surface to a depth of 2.0 cm, and 1.0-MHz US should be used for tissues from 2.0-cm to 5.0-cm depth.

The thermal effects of US are difficult to predict because of the varying rates of absorption by different tissues. Because US is more readily absorbed in bone than in the dermis and muscle, which in turn absorb more US than fat, the heating rate cannot be exactly predicted.^{21,22} In this study, we directly measured the tissue-temperature change in response to US in an area with a large muscle mass. This must be considered when applying the results of the study reported here to tissues having a greater or lesser degree of adipose tissue covering the muscle or areas with superficial bony prominences. US reflection off of bone can create standing waves or "hot spots," which are areas of increased US energy. This may occur when using US over superficial bone, because US energy is

reaching that area from two directions (incoming US and reflection of US off of bone) at the same time.^{4,21}

The thermal effects of US may have relevance in the treatment of a variety of musculoskeletal conditions in the dog. However, unless US is properly used, it has the potential to cause tissue damage such as dermal necrosis or overheating of the deeper tissues, leading to inflammation.^{4,21} Pain experienced during US is usually observed by a withdrawal of the limb or other signs such as whimpering, which are most likely caused by overheating. US should be discontinued immediately if these responses are noticed and the parameters adjusted before continuing treatment.

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