

Hot-Pack and 1-MHz Ultrasound Treatments Have an Additive Effect on Muscle Temperature Increase

David O. Draper, EdD, ATC*; Shane T. Harris, MS, ATC†; Shane Schulthies, PhD, ATC, PT*; Earlene Durrant, EdD, ATC*; Kenneth L. Knight, PhD, ATC*; Mark Ricard, PhD*

*Department of Physical Education, Brigham Young University, Provo, UT 84602; †Preventive and Rehabilitative Sports Medicine, Huntsville, AL

Objective: Therapeutic ultrasound is an effective deep heating modality commonly applied alone or after cooling or heating of the treatment area. The purpose of this study was to examine the tissue temperature rise in the human triceps surae muscle group after ultrasound with prior heating via a silicate gel hot pack.

Design and Setting: This study was designed as a $2 \times 2 \times 3$ factorial with repeated measures on two factors (depth and time). Independent variables were temperature of pack (hot and room temperature), depth of measurement (1 cm and 3 cm), and time (beginning, after pack application, and after ultrasound). The dependent variable was tissue temperature. Subjects were assigned to one of two treatment groups: ultrasound preceded by a 15-minute hot pack treatment or ultrasound preceded by a 15-minute application with a silicate gel pack at room temperature. Measurements were taken while subjects were treated in a university training room.

Subjects: Twenty-one uninjured male and female college student volunteers were randomly assigned to one of the two pack groups.

Measurements: The hot packs were stored in 75°C water. A 1-MHz ultrasound treatment was administered for 10 minutes

at an intensity of 1.5 W/cm². Tissue temperature was measured every 30 seconds using 23-gauge hypodermic microprobes interfaced with a telethermometer and inserted 1 and 3 cm below the surface of anesthetized triceps surae muscle.

Results: At both tissue depths, there was a 0.8°C greater increase in tissue temperature with hot packs and ultrasound. At 1 cm, ultrasound increased temperature 3.5°C after a 0.5°C rise during the room temperature-pack application, but only 0.6°C after a 3.8°C increase during hot-pack application. At 3 cm, ultrasound increased temperature 3.85°C following a slight (-0.26°C) decrease during the room temperature-pack application and 3.68°C after a 0.74°C increase during hot-pack application.

Conclusions: Vigorous increases in deep muscle temperature ($\geq 4^\circ\text{C}$) can be reached with 2 to 3 minutes less total sonation time when preheated with a hot pack. Thus, ultrasound and hot packs have an additive effect on intramuscular temperature, but the characteristics of the additive effect are different, primarily because there appears to be a tissue temperature plateau.

Key Words: tissue temperature rise, superficial heating

Therapeutic ultrasound is used to treat a variety of conditions.¹⁻⁶ It is often used as a thermal modality when treating soft tissue injuries because it selectively heats structures up to 5 cm deep with only minimal increases in skin temperatures.⁷ There have been many studies on the independent use of ultrasound and its effects on deep tissue temperature elevation.^{6,8-12} We found few studies, however, that examined the effect of heat¹³ or cold^{14,15} combined with an ultrasound treatment. The one study we found that looked at combined hot pack and ultrasound (human thigh) indicated that hot packs neither enhanced nor diminished the deep heating effects of ultrasound.¹³ Those researchers applied the hot pack only for 8 minutes, which may have been too brief to produce tissue heating.

Since the standard application time for hot packs is 15 minutes, we feel Lehmann et al¹³ did not adequately investi-

gate the subject. If indeed there is no additional benefit of preceding ultrasound application with hot packs, those who use the technique are wasting time. On the other hand, if there is an added benefit, clinicians should be informed of such and alter their protocols accordingly. Our purpose, therefore, was to reinvestigate the superficial and deep heating effects of ultrasound treatment after a 15-minute hydrocollator heat pack treatment.

METHODS

A $2 \times 2 \times 3$ factorial design with repeated measures on two variables (time and depth) guided this experiment. Our dependent variable was tissue temperature. The independent variables were the treatment methods (hot pack and room temper-

ature pack), tissue depth (1 cm and 3 cm below surface), and time (preapplication, postpack, and postultrasound).

Twenty-one male and female subjects (age = 23.7 ± 1.7 yr) volunteered for this study. Data from one subject could not be used due to a thermistor malfunction. Subjects' left triceps surae muscles were free from ecchymosis, infection, swelling, and injury for at least 6 months prior to the experiment and had less than 15 mm skinfold. Each subject read and signed a consent form approved by the Brigham Young University Human Subjects Review Board.

We used an Omnisound 3000 (Physio Technology Inc, Topeka, KS) ultrasound unit at 1 MHz. Its transducer head was 5 cm² and housed a lead zirconate titanate crystal, with a beam nonuniformity ratio of 1.8:1 and an effective radiating area of 4.1 cm² (manufacturer's specifications). Our conducting medium was Ultraphonic Conductivity Gel (Pharmaceutical Innovations Inc, Newark, NJ) at room temperature (25°C). We used a template (2 times the size of the effective radiating area of the applicator) to ensure that the treatment size was consistent throughout the experiment.¹⁶

Two 23-gauge thermistor needles (Phystek MT-23/5, Physitemp Instruments, Clifton, NJ) were attached to a monitor (Bailey Instruments BAT-12, Physitemp Instruments, Clifton, NJ) that displayed the temperature in degrees Celsius. We recorded intramuscular temperature every 30 seconds. Surface temperature was monitored, but not recorded, with a surface thermocouple (TK80) attached to a multimeter with a temperature module (model 73, Fluke Co, Everett, WA).

Packs for the room-temperature treatment were stored in an unplugged hydrocollator (model M2, Chattanooga Corporation, Hixson, TN). We used a 25 × 30 Tropic Pac (J.A. Preston Corporation, Jackson, MI) silicate gel/canvas hot-pack cover. Packs for the hot pack group were heated 75°C in an identical hydrocollator and wrapped in a standard terry cloth cover. Subjects were provided extra toweling as needed for comfort (8 subjects required an additional 1.6 layers of toweling).

With the subject lying prone on a table, a 10-cm diameter treatment area on the left medial triceps surae muscle group was shaved, cleansed thoroughly with a Betadine scrub (The Purdue Frederick Company, Norwalk, CT), and swabbed with 70% isopropyl alcohol. An injection of 1 cc of 1% lidocaine was administered at depths of 1 and 3 cm beneath the surface of the treatment site to anesthetize the area. The injection sites were located by measuring down from the upper surface of the muscle belly using a T-square. Thermistors, sterilized in a solution of Cidex (Johnson & Johnson Medical, Arlington, TX) for 15 min¹⁷ before each use, were then inserted at 1 and 3 cm below the skin's surface through the injection sites. Three- and five-centimeter length thermistors were used at the 1- and 3-cm depths, respectively, to ensure that the tip of each thermistor was directly below the treatment site. A bubble level was used while inserting the thermistors to ensure that the probes were level with the skin surface and inserted at the proper depth. The thermistors were then connected to the monitor, and we waited

for the temperature to stabilize (approximately 1 to 3 minutes) and recorded this temperature as the baseline.

We randomly assigned subjects to either the hot-pack/ultrasound group or the room temperature-pack/ultrasound group. After recording a baseline temperature, the pack was placed on the posterior triceps surae muscle belly (directly above the thermistors) for 15 minutes, and temperature was recorded at each depth every 30 seconds.

Ultrasound application began 1 minute after the hot-pack treatment. We attached the ultrasound template to the calf directly above the thermistor tips and applied 15 mL of ultrasound gel to the treatment area (Fig 1). Continuous ultrasound, at a frequency of 1 MHz and an intensity of 1.5 W/cm², was applied for 10 minutes. The sound head was moved at approximately 4 cm/sec within the template. The room temperature-pack/ultrasound treatment followed the same procedures as the hot-pack/ultrasound treatment except a 25°C silicate gel pack was used in place of the hot pack. When the treatment was concluded, we removed the thermistors from the subject's leg. The area was again cleansed with a Betadine solution and an adhesive bandage applied over the insertion sites.

We computed tissue temperature change scores during each of three time periods: during pack application, during ultrasound application, and total (sum of pack and ultrasound application scores). These were computed as the differences between the beginning and ending temperatures for each of the time periods. We analyzed the data with two $2 \times 2 \times 3$ analyses of variance (ANOVAs) with repeated measures on depth and time. For one ANOVA, the dependent variable was the raw temperature score at the beginning of pack application, the end of pack application (which was the beginning of ultrasound application), and the end of ultrasound application. The second ANOVA was computed using temperature change scores as the dependent variable. Significant main effects were further analyzed with Tukey post hoc tests for those

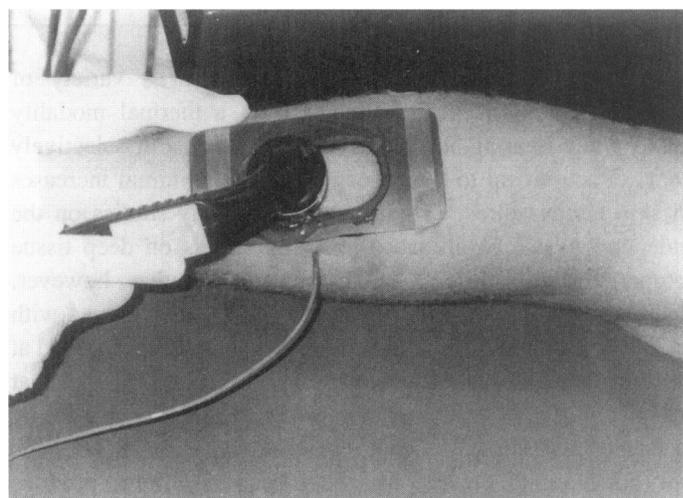


Fig 1. Ultrasound to the muscle belly, guided by a template that is two times the effective radiating area. Note the thermistor probe below the template.

comparisons between depth and modality (time) and Scheffe post hoc tests for the comparisons between packs because the latter had unequal cell means. The alpha level for all tests was set at 0.05.

RESULTS

Tissue temperature increased significantly in superficial and deep tissues during both hot pack and ultrasound application (Table 1; $F(1,17) = 11.1, P = .004$). Although hot packs and ultrasound had an additive effect at both depths, the effects were not linear (Fig. 2); the hot pack appeared to moderate the effects of the ultrasound. For instance, at 1 cm, ultrasound increased temperature 3.5°C after a 0.5°C rise during the room temperature-pack application. But following a 3.8°C increase during hot-pack application, ultrasound added only 0.6°C. At 3 cm, there was no difference in effects of the ultrasound following the two pack conditions, but hot packs increased only the deeper temperature 0.7°C (Table 2). The difference in the overall heating at 3 cm was the result of the tissue temperature rise of the hot pack and the slight cooling effect of the room temperature pack. There was no difference in total temperature rise at the two tissue depths (Table 2).

Although we did not record specific times, we did observe that the temperature at the surface of the skin would level out and begin to decrease at about 8 minutes into hot-pack treatment, as Lehmann et al¹⁸ reported. The temperature at 1 and 3 cm, however, continued to rise gradually throughout hot-pack application.

DISCUSSION

The additive effect of hot packs and ultrasound are both enlightening and complicated. They are enlightening because our results contradict those of Lehmann et al,¹³ who reported no additive effect of hot packs and ultrasound. They applied hot packs for only 8 minutes before the ultrasound treatment. This time was selected because in previous research hot-pack

Table 1. Triceps Surae Muscle Temperature (at 1-cm and 3-cm depths) Before and After 15-Minute Treatments of Room Temperature Packs or Hot Packs Followed by 10 Minutes of 1-MHz Ultrasound (°C; Mean ± SD)

	n	Application		
		Pre	Post Pack	Post US
1 cm Deep				
Room temp pack	9	34.6 ± .5*	34.7 ± .6*	38.2 ± .5†
Hot pack	11	34.1 ± .7*	37.9 ± .7‡§	38.6 ± 1.0
3 cm Deep				
Room temp pack	9	35.9 ± .2	35.6 ± .3	39.5 ± .8†
Hot pack	11	35.7 ± .7	36.5 ± .4‡	40.2 ± .8‡

* 1 cm Deep < 3 cm Deep ($P < .05$).

† Post US > Post Pack and Pre Application ($P < .05$).

‡ Hot Pack > Room Temp Pack ($P < .05$).

§ 1 cm Deep > 3 cm Deep ($P < .05$).

|| Post US > Post Pack > Pre Application ($P < .05$).

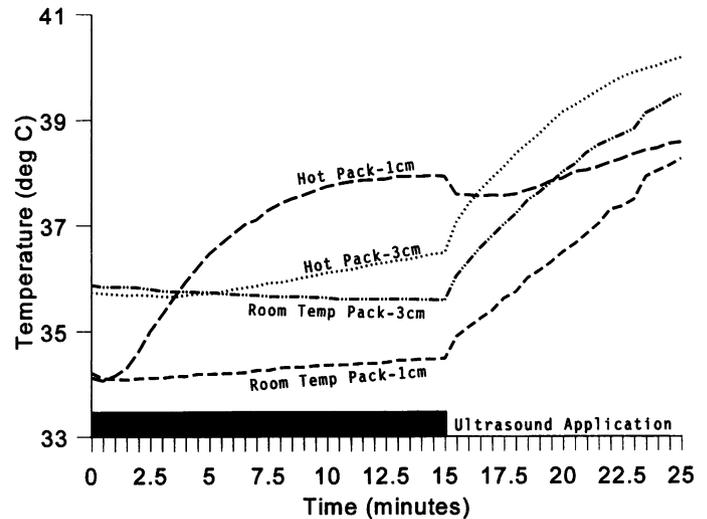


Fig 2. Mean tissue temperature rise of the triceps surae muscle group at 1 and 3 cm following ultrasound preceded by a hot or room temperature pack.

Table 2. Tissue Temperature Change at 1-cm and 3-cm Depths During Application of 1 MHz Ultrasound Following Either Room Temperature Pack or Hot Pack Application (°C; Mean ± SD)

	n	Temperature Rise during application of:		
		Packs (15 min)	US (10 min)	Total (25 min)
1 cm Deep				
Room temp pack*		.15 ± .38†	3.50 ± .37†	3.65 ± .49†
Hot pack‡		3.83 ± 1.17§	.61 ± .80§	4.44 ± 1.09
3 cm Deep				
Room temp pack*		-.26 ± .21†	3.85 ± .65	3.58 ± .73†
Hot pack‡		.74 ± .59	3.68 ± .76	4.42 ± .85

* Difference between conditions (Total and US > Pack).

‡ Difference between conditions (Total > US > Pack).

† Difference between packs (Hot Pack > Room Temp Pack).

§ Difference between depths.

applications to the human thigh produced peak surface temperatures at 8 minutes into the treatment.¹⁸ We believe this time was insufficient to obtain the benefits of both treatments. We observed that surface temperature leveled out and decreased at about 8 minutes into our hot-pack treatment, which is similar to the findings of Lehmann et al,¹⁸ however, in both our study and theirs, deeper temperatures (1 and 3 cm) continued to rise throughout the 15-minute treatment.

Lehmann et al,¹³ therefore, did not receive the full benefits of the hot pack at the deeper levels before application of the ultrasound. Of the 11 subjects who underwent the hot-pack/ultrasound treatment, 82% (9) had a temperature increase of 4°C or greater at 3 cm. Of the 9 subjects who underwent the room temperature-pack/ultrasound treatment only 22% had an increase of 4°C or greater at 3 cm. If Lehmann et al¹³ had left the hot pack on longer, their findings might have been similar to ours.

Our results are complicated because the additive effect we observed at 3 cm did not occur at 1 cm. The ultrasound during

the room temperature-pack/ultrasound treatment had an average temperature rise of 3.50°C at 1 cm.

Ultrasound produced a 3.50°C increase after room temperature packs, but only a 0.61°C increase after hot-pack application. It seemed as if the tissue had a plateau, and the closer the temperature got to the plateau, the quicker the body carried away the heat added to the tissue. This idea is consistent with the "set point" concept presented by Guyton and Hall.¹⁹ Central and local mechanisms and reflex arcs continually attempt to maintain the core temperature at a set point established by the hypothalamus. Although local temperature is allowed to vary more than core temperature, it still has limits, so excessive heat exchange from locally heated or cooled portions of the body is prevented.

The 3.4°C increase at 1 cm by the hot pack was greater than the 3.0°C seen by Lehmann et al¹³ and the 2.2°C reported by Halvorson.²⁰ This hot-pack increase was almost equal to the tissue temperature rise of 10 minutes of ultrasound alone (3.6°C). For joints whose capsule is within 1 cm of the surface, where only moderate heating is desired, either hot packs or ultrasound are acceptable.

It would be interesting to examine the effect of 3-MHz ultrasound with prior heating on tissue temperature rise in superficial tissues. With 3-MHz ultrasound, most of the energy is absorbed in the first 1 or 2 cm.^{16,21,22} Both the hot pack and 3-MHz ultrasound are superficial heating modalities, so substantial heating could occur. There are many superficial muscles, tendons, and ligaments that could benefit from treatment methods of this kind.

In conclusion, our study has revealed the following:

1. Overall temperature increases occurred with application of both hot pack and ultrasound.
2. The hot pack made more of a profound impact in temperature increase at 1 cm.
3. The ultrasound made more of a profound impact in temperature increase at 3 cm.
4. The overall heating at 1 cm was greater than at 3 cm.
5. Hot packs reached their maximum heating effect at 15 minutes application (this contradicts the findings of Lehmann et al¹³).
6. Vigorous increases in deep muscle temperature ($\geq 4^\circ\text{C}$) can be reached with 2 to 3 minutes less total sonation time when the area is preheated with a hot pack. This decreased sonation time may possibly prevent the periosteal irritation that sometimes accompanies ultrasound treatments of long duration. Also, the clinician may be free to work on other patients while one is undergoing preheating via a hot pack.

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