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Heat Distribution in the Lower Leg from Pulsed Short-Wave Diathermy and Ultrasound Treatments

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Objective: To compare tissue temperature rise and decay after 20-minute diathermy and ultrasound treatments.

Design and Setting: We inserted 3 26-gauge thermistor microprobes into the medial aspect of the anesthetized triceps surae muscle at a depth of 3 cm and spaced 5 cm apart. Eight subjects received the diathermy treatment first, followed by the ultrasound treatment. This sequence was reversed for the remaining 8 subjects. The diathermy was applied at a frequency of 27.12 MHz at the following settings: 800 bursts per second, 400-microsecond burst duration, 850-microsecond interburst interval, peak root mean square amplitude of 150 W per burst, and an average root mean square output of 48 W per burst. The ultrasound was delivered at a frequency of 1 MHz and an intensity of 1.5 W/cm^2 in the continuous mode for 20 minutes over an area of 40 times the effective radiating area. The study was performed in a ventilated research laboratory.

Subjects: Sixteen (11 men, 5 women) healthy subjects (mean age = 23.56 ± 4.73 years) volunteered to participate in this study.

Measurements: We recorded baseline, final, and decay temperatures for each of the 3 sites.

Results: The average temperature increases over baseline temperature after pulsed short-wave diathermy were 3.02°C ± 1.02°C in site 1, 4.58°C ± 0.87°C in site 2, and 3.28°C ± 1.64°C in site 3. The average temperature increases over baseline temperature after ultrasound were only 0.17°C ± 0.40°C, 0.09°C ± 0.56°C, and −0.43°C ± 0.41°C in sites 1, 2, and 3, respectively. The temperature dropped only 1°C in 7.65 ± 4.96 minutes after pulsed short-wave diathermy.

Conclusions: We conclude that pulsed short-wave diathermy was more effective than 1-MHz ultrasound in heating a large muscle mass and resulted in the muscles' retaining heat longer.

Key Words: modalities, tissue temperature, stretching window

Heat has been used for many years as a therapeutic modality for the treatment of injured muscle tissue. Heating modalities can be classified as either superficial or deep heating. Examples of superficial agents include silicate gel hot packs, whirlpool, and paraffin baths; these modalities primarily cause an increase in skin and subcutaneous tissue temperature in structures up to 1 cm below the skin's surface.[1] The 2 most-recognized deep-heating modalities are ultrasound and diathermy. Deep-heating agents can heat structures at depths of 3 cm to 5 cm without overheating the overlying structures of skin and subcutaneous tissues.[2,3]

When choosing the appropriate thermal modality, one must consider not only target tissue depth, but also the location and size of the area to be treated. An ultrasound treatment is measured by a unit called effective radiating area (ERA). The ERA is slightly smaller than the size of the ultrasound transducer faceplate. Ultrasound effectively heats an area approximately twice the size of the soundhead (a relatively small area).[3,4] Since a diathermy applicator is relatively large compared with an ultrasound head, both diathermy and ultrasound effectively heat small regions of the body.[5,6] For years, it has been assumed that diathermy can heat a much larger area than ultrasound and that the heat is retained significantly longer. Our purpose was to compare the differences in peak muscle temperatures obtained after a 20-minute inductance pulsed short-wave diathermy application and a 20-minute ultrasound application over the same size area.

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METHODS

In our study, the dependent variable was change in tissue temperature, and the 2 independent variables were site and treatment. Site had 3 levels: proximal (probe 1), middle (probe 2), and distal (probe 3). Treatment had 2 variables: diathermy and ultrasound.

Subjects

The Institutional Review Board at Brigham Young University approved this study before data collection. Sixteen students (11 men, 5 women; average age = 23.56 ± 4.73 years) volunteered to participate and gave informed consent. Subjects were screened for allergy to lidocaine and examined for possible contraindications such as open wounds or acute swelling. We also measured the subjects' posterior triceps surae muscles to make sure the diameter was no less than 10

cm and no greater than 20 cm at the widest point. This was done to ensure that the subjects' muscle mass was large enough to complete the procedure, as well as to eliminate subjects with excess subcutaneous fat that could skew the results. Each subject was assigned a code number to ensure confidentiality.

Instruments

We used the Megapulse diathermy unit (Accelerated Care Plus-LLC, Topeka, KS) with a frequency of 27.12 MHz. This device heats via a 200-cm^2 induction coil drum electrode with a 2-cm space plate. We used the Omnisound 3000C ultrasound unit (Accelerated Care Plus-LLC) with a 5-cm^2 transducer and a beam nonuniformity ratio of 1.4:1. Both of these machines were new and had been calibrated by the manufacturer before our study. We used Aquasonic 100 gel (Parker Laboratories, Orange, NJ) as our ultrasound couplant.

Three 26-gauge thermistor needles (Phystek MT-26/5; Physiotemp Instruments, Clifton, NJ) were used to measure the muscle temperature. An Isothermix (Columbus Instruments, Columbus, OH) interfaced with a 486 computer was used to display the temperatures in degrees Celsius every minute. The accuracy of the temperature recordings of the probes was within 0.1°C, and the monitor was accurate to within 0.1°C (manufacturers' data). At most, the measurement error would be ± 0.2°C.

Procedures

Each subject was asked to lie prone on the table for the duration of the study. The subject's left medial triceps surae complex was cleansed with alcohol. The widest portion of the posterior surface of the muscle was determined. We used a measuring caliper to plot medially to a depth of 3 cm in the site where the thermistor was to be inserted and then made a pen mark in this area (Figure 1). A template with 3 holes spaced 5 cm apart was placed on the skin, with the center hole over the pen mark (Figure 2). Through the template, the proximal and distal sites were marked. The template was removed, and again the area was cleansed. An injection of 1 cc of 1% Xylocaine (Astra USA, Inc, Westborough, MA) was administered in each of the 3 sites. After 2 minutes, 3 sterile thermistors were inserted with a hemostat into the triceps surae muscle in the same holes where the injections had been given (Figure 3).

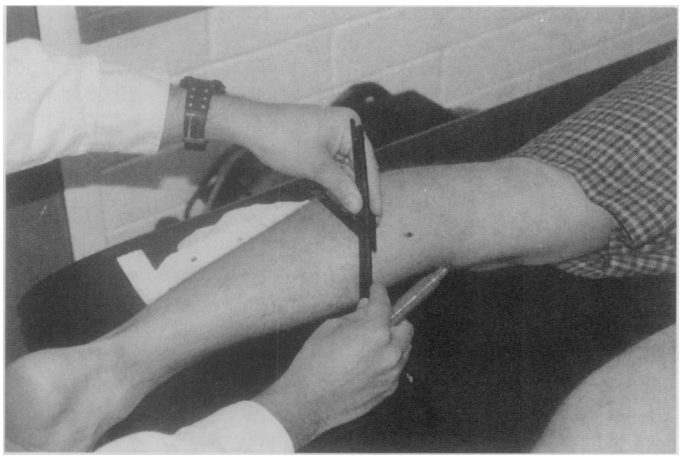

Figure 1. Medial plot to a depth of 3 cm for thermistor insertion, with pen mark.

Figure 2. Three-hole template placed on the skin, with the center hole over the pen mark.

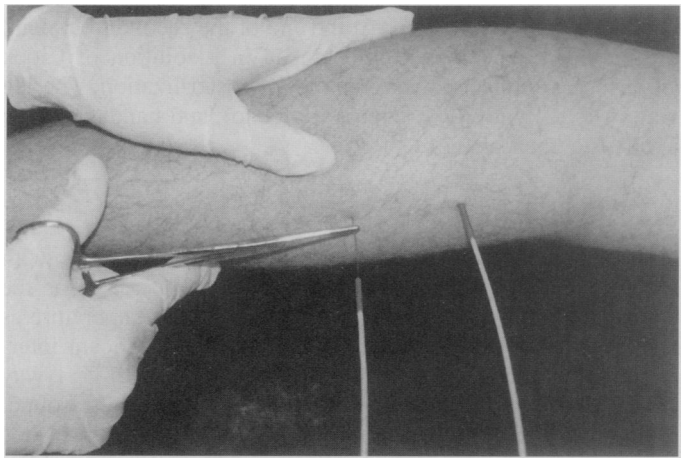

Figure 3. Sterile thermistors inserted into the triceps surae muscle.

After achieving a baseline temperature (about 2 minutes' time), a method of randomization was employed, and the sequence of the study was determined. Each sequence contained a 20-minute diathermy treatment, a rest time for the temperature to return to baseline, and a 20-minute ultrasound treatment. Eight subjects had diathermy followed by ultrasound, and 8 subjects had ultrasound followed by diathermy.

For the diathermy treatment, the middle of the drum was placed directly over the middle probe (Figure 4). A 20-minute pulsed short-wave diathermy treatment was then administered at the following parameters: 800 bursts per second, 400-microsecond burst duration, 850-microsecond interburst interval, peak root mean square amplitude of 150 W per burst, and an average root mean square output of 48 W per burst. At the end of the 20-minute treatment, the peak or terminal temperature was recorded, and the rate of temperature decrease was recorded each minute until the pretreatment baseline was reached.

The ultrasound treatment area was designated by tracing the circumference of the diathermy drum's surface onto the skin. The area resulted in a 40-ERA (200 cm^2 surface area/5 cm^2 head) treatment for ultrasound. A 20-minute ultrasound application was then given at the following parameters: continuous 1 MHz, 1.5 W/cm^2, applied using longitudinal strokes at a rate of 4 cm/s (Figure 5). We recorded temperature each minute during the treatment and each minute after until the pretreat-

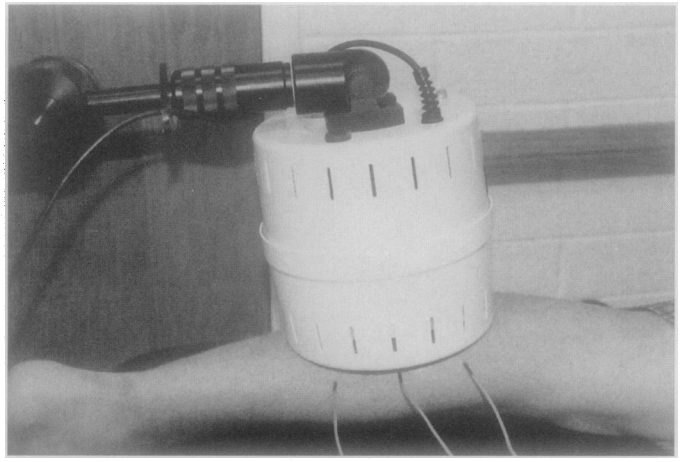

Figure 4. The middle of the drum was placed directly over the probe for the diathermy treatment.

ment baseline was reached. At the end of the second treatment, the probes were removed and placed in a solution of Cidex (Johnson & Johnson, Arlington, TX) for sterilization. The leg was swabbed with 70% isopropyl alcohol, and bandages were applied to each of the 3 sites.

Statistical Analysis

We computed 2 2-way analyses of variance (ANOVAs) with repeated measures using change in tissue temperature as the dependent variable, followed by baseline tissue temperature as the dependent variable. Because there was a significant interaction, the simple main effects were tested with 5 1-way ANOVAs, 1 for each level of independent variable: ultrasound, diathermy, site 1, site 2, and site 3. We used Tukey post hoc tests to identify significant differences between variables. Alpha was set at 0.05 for all comparisons. We calculated an independent-samples *t* test for baseline temperatures to look at order of treatment.

RESULTS

Diathermy heated the calf muscle significantly more than ultrasound ($F_{1,75} = 409.59$, $P < .0001$) (Table 1). We noted a significant interaction between modality and site ($F_{2,75} = 6.81$, $P < .0019$), so additional results are based on simple main-effects testing. Site had an effect on the change in the tissue temperature ($F_{2,75} = 9.43$, $P < .0002$); site 2 displayed a more significant change in temperature than sites 1 and 3 (Tukey, $P < .05$).

Overall, ultrasound baseline temperatures were greater than diathermy baseline temperatures ($F_{1,75} = 31.66$, $P < .0001$). There was also a significant difference in baseline temperatures among sites ($F_{2,75} = 15.79$, $P < .0001$). With both diathermy and ultrasound, the baseline temperature for site 3 was less than that for sites 1 and 2 ($P < .05$). Order of application appeared to affect the results: when diathermy was administered first, a difference in baseline temperatures was found for sites 2 ($t_7 = 4.04$, $P < .0012$) and 3 ($t_7 = 4.41$, $P < .0006$) (Table 2).

Temperature decay time was calculated for all 3 sites after diathermy and ultrasound. Ultrasound decay time averaged 14.88 ± 4.70 minutes to return to baseline temperature. After diathermy, the temperature returned to baseline in 38.50 ± 6.61 minutes, dropping 1°C in 7.65 ± 4.96 minutes, 2°C in 16.30 ± 9.06 minutes, and 3°C in 22.8 ± 9.2 minutes.

Table 1. Mean Temperatures at 3 Sites Using Ultrasound and Diathermy (°C)

	N	Site 1	Site 2	Site 3
Ultrasound				
Baseline*†	16	36.44 ± 0.32	36.36 ± 0.58	35.78 ± 0.73
Final	16	36.61 ± 0.56	36.44 ± 0.79	35.30 ± 0.82
Change†‡	16	0.17 ± 0.40	0.09 ± 0.55	−0.43 ± 0.41
Diathermy				
Baseline*†	16	35.93 ± 0.60	35.67 ± 0.77	35.20 ± 0.97
Final	16	38.94 ± 0.87	40.26 ± 0.70	38.48 ± 1.44
Change‡§	16	3.02 ± 1.02	4.58 ± 0.87	3.28 ± 1.63

*Ultrasound > diathermy ($P < .05$).
†Sites 1 & 2 > site 3 ($P < .05$).
‡Diathermy > ultrasound ($P < .0001$).
§Site 2 > sites 1 & 3 ($P < .05$).

DISCUSSION

Ultrasound uses acoustic energy, which can penetrate cell membranes and produce an increase in tissue temperature.[1]

Table 2. Mean Temperatures at 3 Sites Using Diathermy and Ultrasound by Order (°C)

	n	Site 1	Site 2	Site 3
Diathermy first				
Baseline	8	36.20 ± 0.57	36.22 ± 0.51*	35.91 ± 0.56†
Final	8	39.25 ± 0.99	40.43 ± 0.86	39.06 ± 1.53
Change	8	3.05 ± 1.25	4.21 ± 0.93	3.14 ± 1.74
Diathermy second				
Baseline	8	35.65 ± 0.51	35.13 ± 0.57	34.48 ± 0.74
Final	8	38.64 ± 0.64	40.09 ± 0.49	37.90 ± 1.17
Change	8	2.99 ± 0.81	4.96 ± 0.65	3.42 ± 1.64
Ultrasound first				
Baseline	8	36.44 ± 0.29	36.22 ± 0.54	35.90 ± 0.58
Final	8	36.64 ± 0.29	36.30 ± 0.38	35.47 ± 0.55
Change	8	0.20 ± 0.38	0.09 ± 0.54	−0.44 ± 0.44
Ultrasound second				
Baseline	8	36.44 ± 0.37	36.49 ± 0.63*	35.66 ± 0.87†
Final	8	35.57 ± 0.76	36.58 ± 1.08	35.24 ± 1.06
Change	8	0.14 ± 0.45	0.09 ± 0.62	−0.42 ± 0.42

*$t_7 = 4.04$, $P < .0012$.
†$t_7 = 4.41$, $P < .0006$.

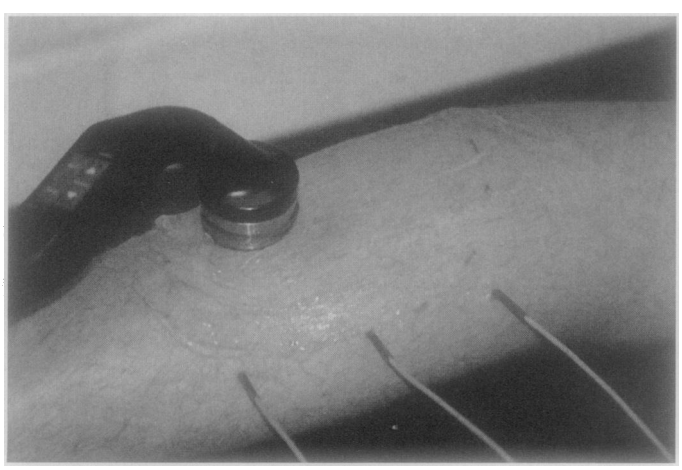

Figure 5. Ultrasound application.

Diathermy uses electromagnetic energy rather than acoustic energy to generate heat in the body tissues due to the resistance offered by the tissues.[3,7] Benefits derived from a diathermy treatment are those of heat in general: primarily tissue temperature rise, increased blood flow, muscle relaxation, alterations in the physical properties of fibrous tissues, and a heightened pain threshold.[1,8–10]

The use of diathermy has dwindled dramatically since the advent of ultrasound.[7] Its decline has sometimes been blamed on poorly constructed machines, which yielded complaints such as patient burns and hot spots.[11–14] Other reasons for diathermy's drop in popularity among allied health professionals include lack of dosage measurement,[12,15] complexity of efficient and effective electrode placement,[7,12] long treatment times,[2,7] overheating of subcutaneous fat,[7,16] and high cost of equipment.[2] Since both diathermy and ultrasound are used to increase deep muscle temperature and since ultrasound has fewer contraindications than diathermy, clinicians have replaced diathermy with ultrasound. As a result, ultrasound is often overused and abused.[17,18] In the past decade, diathermy technology has advanced, however, so much of the research available on diathermy is outdated. These advancements include better shielding from electromagnetic waves,[19] ease of electrode or drum placement, and a decrease in hot spots and burns.

Our investigation expands diathermy research by identifying situations where diathermy would be more beneficial than ultrasound, specifically for areas of the body too large to be effectively heated by ultrasound. Three important questions have been answered by our study: 1) Does the entire surface of the diathermy drum produce significant heating in deep muscle tissue? 2) Are the heating rates of pulsed short-wave diathermy and an ultrasound treatment over the same-size areas similar? 3) Will tissues heated by pulsed short-wave diathermy and ultrasound over the same-size area retain heat at similar rates?

Size of Heating Area

Lehmann[20] suggested that, in order to cause moderate to vigorous heating in tissues, temperature increases of 2°C to 4°C are required. According to Michlovitz et al,[21] optimal thermal effects of increased metabolism and blood flow with reduced pain and muscle spasm occur when peak tissue temperatures of 40°C to 45°C are reached and maintained for 5 minutes.

As the size of the ultrasound treatment area increases, the rate of temperature increase slows. In a recently completed study,[4] researchers looked at the differences in muscle temperature between a 2-ERA and a 6-ERA ultrasound treatment, at intensities of 1.5 W/cm^2 and 2.0 W/cm^2 of 10 minutes' duration. Although the 2 intensities did not result in different muscle temperatures, a significant difference in heating did exist between the 2 treatment sizes. The mean temperature change from the 2-ERA treatment was 3.5°C, compared with only 1.3°C for the 6-ERA treatment.[4]

Temperature changes in patellar tendons during ultrasound are also affected by the size of the heating area. A recent study compared ultrasound over areas of 2 ERA and 4 ERA. Although both treatments increased patellar tendon temperature, the 2-ERA treatment size produced higher temperature increases (8.3°C) and longer heat retention than the 4-ERA treatment size (5.0°C).[22]

When we applied ultrasound to a 40-ERA treatment size, none of the probes measured muscle temperature increases greater than 0.2°C (Table 1). During the diathermy treatment, however, each of the 3 probes measured muscle temperature increases greater than 3°C (moderate to vigorous heating). Two important conclusions with respect to treatment size can be drawn from our study. First, 1-MHz continuous ultrasound at 1.5 W/cm^2 was not effective in heating areas as large as a diathermy drum (Figure 5). Second, diathermy heated areas as large as the surface of the drum applicator (Figure 4).

Like the Megapulse used in our study, a typical diathermy drum has a surface area of 200 cm^2; ultrasound heads range from 3 cm^2 to 10 cm^2. It is not surprising, therefore, that, when ultrasound is applied to an area the same size as a diathermy drum, the temperature increase is negligible. Current research in humans[4,22] substantiates the recommendation that an ultrasound treatment should cover an area no larger than 2 to 3 times the size of the transducer. When these treatment-size recommendations are followed, vigorous heating results.

We noted that heat distribution under the diathermy drum was not equal. The center probe measured an increase of 4.6°C, whereas the outer probes peaked at 3.1°C and 3.4°C. We speculate that cooling may have occurred more on the outer edges of the heated muscle due to conduction to cooler tissues not under the drum applicator. The tissues under the center of the drum stayed warmer due to conduction of heat from the surrounding tissues.

Peak Heating

The final temperatures of 40-ERA ultrasound and pulsed short-wave diathermy of the same surface area were not equal when we tried to heat large areas of the body. When ultrasound treatment size is 2 ERA, the final temperatures of ultrasound and pulsed short-wave diathermy are very similar in the center of the respective treatment areas. During a recently completed study,[23] after 10 minutes of pulsed short-wave diathermy, the muscle temperature increased an average of 2.87°C. After 10 minutes of 1-MHz ultrasound at 1.5 W/cm^2, the temperature increased 3°C over baseline in an area twice the size of the soundhead.[5] Comparing these 2 studies, we see that the heating rates of pulsed short-wave diathermy and ultrasound are quite similar at the center of the application when ultrasound is applied to an area of 2 ERA.

Temperature Decay

One of the purposes of heating an area with diathermy or ultrasound is to increase range of motion that has been limited by periarticular connective tissue changes such as joint contracture and scar tissue.[1,3] The period of vigorous heating when tissues will undergo the greatest extensibility and elongation is referred to as the "stretching window." If tissue is vigorously heated, it becomes more pliable and less resistant to stretch. Yet as the tissue cools, it withstands stretching and can actually be damaged if too great a force is applied.

This concept of heat and stretch prompted 2 studies regarding the optimal time period in which these techniques should occur. The first study[24] involved the rate of temperature decay after 3-MHz ultrasound 1.2 cm deep in the muscle. After temperature increased at least 5°C over baseline, the ultrasound treatment was terminated, and decay time was recorded. The temperature dropped 1°C in

1.3 minutes, on average.[24] A follow-up to this study looked at thermal decay after a 1-MHz ultrasound treatment.[25] This time, the temperature peaked at a 4°C increase over baseline at a depth of 2.5 cm. At the end of the ultrasound treatment, the average time for the temperature to drop 1°C was 2.5 minutes. The area of 1-MHz treatment retained the heat almost twice as long as the area of 3-MHz treatment.[25]

In our study, after diathermy, the temperature at the center probe required 7.65 ± 4.96 minutes to decay 1°C; thus, muscle heated with pulsed short-wave diathermy retained its heat more than 3 times longer than muscle heated with ultrasound. Why is there a longer stretching window after pulsed short-wave diathermy? We believe this slow heat loss is also associated with conductive heating of surrounding tissues. When a large area is heated, the tissues at the periphery conduct heat to the surrounding tissues; thus, they retain heat longer. Since a pulsed short-wave diathermy treatment produces longer heat retention than ultrasound, clinicians using pulsed short-wave diathermy can more effectively incorporate stretching and therapeutic exercises into their treatment goals.

Our Results Compared With Others'

Our data compare favorably with previous studies on diathermy. In 1 study,[26] 20 minutes of microwave diathermy with different machines resulted in mean temperature increases of 4.3°C and 4.6°C. These values are not only within the therapeutic range for tissue temperature increase, but also within 0.3°C of our results (middle probe). Yet comparisons cannot be drawn since those probes were of 5-cm depth in the quadriceps muscle and since microwave diathermy was used. A more recent study[23] also noted favorable results after 20 minutes of pulsed short-wave diathermy. A mean temperature increase of 3.49°C ± 1.13°C was recorded in the human gastrocnemius-soleus complex. This study, however, used only 1 probe; thus, treatment-area size was not examined.

Benefits derived from a diathermy treatment are those of heat in general: primarily tissue temperature rise; increased blood flow; blood vessel dilation; increased filtration and diffusion through the different membranes; increased tissue metabolic rate; changes in some enzyme reactions; alterations in the physical properties of fibrous tissues (such as those found in tendons, joints, and scars); a certain degree of muscle relaxation; and a heightened pain threshold.[1,9] Athermal effects may occur at the cell membrane when a diathermy treatment is pulsed,[3] but diathermy is used primarily to heat large areas of the body.

Ultrasound, when used therapeutically, is similar to diathermy in many respects. It can heat tissues to depths of 3 cm to 5 cm or more. The use of ultrasound in rehabilitation is also indicated for conditions such as joint contractures, scar tissue, tendinitis, bursitis, skeletal muscle spasms, and pain.[3] Ultrasound is also frequently used for its nonthermal effects. These include cavitation, which can result in diffusional changes along the cell membranes, and acoustical streaming, which increases cell membrane and vascular wall permeability.[3] Ultrasound is used for its thermal and nonthermal effects but should be limited to areas no larger than 2 times the transducer size to be effective.[3]

CONCLUSIONS

In the past, it has been assumed that diathermy heats a larger area than ultrasound because the diathermy drum is larger than the ultrasound head. This premise, however, has not been proved until now. We were able to show that diathermy does, in fact, heat a larger treatment area than ultrasound and would be more effective than ultrasound in delivering heat for conditions such as chronic hamstring pulls, low back pain, and gluteal and piriformis muscle strains. Although ultrasound is a good deep-heating modality for a variety of conditions, diathermy should be considered for its many advantages in certain circumstances. First, diathermy appears to heat tissues at the same rate as ultrasound, but it affects a much larger area and the clinician need not be present during the entire treatment session. Second, with ultrasound, as the treatment size increases, the rate of heating decreases. We found that diathermy achieved vigorous heating throughout the entire treatment area, thus enabling a large area to be effectively heated. Finally, due to the large area that was heated, the muscle retained the heat much longer after a diathermy treatment, thus lengthening the stretching window.

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