Examination Of The Law Of Grotthus-Draper: Does Ultrasound Penetrate Subcutaneous Fat In Humans?

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Abstract: *One benefit of ultrasound over infrared modalities is its ability to penetrate subcutaneous fat. The purpose of this study was to compare tissue temperature rise during ultrasound treatments in humans with various thicknesses of subcutaneous fat in the medial gastrocnemius. Twenty males served as subjects. A 23-gauge hypodermic needle microprobe was inserted 3-cm deep into the medial portion of the anesthetized gastrocnemius, and connected to a thermocouple temperature gauge. We applied 15 ml of ultrasound gel, preheated to body temperature (37°C), to a 10-cm-diameter target area. Continuous ultrasound was delivered topically at 1.5 W/cm^2 for 10 minutes. During this time, the soundhead was moved at a speed of 4 cm per second, and the temperature was recorded every 30 seconds. The mean baseline temperature for all subjects was 35.4°C. The mean temperature increase was 4.9°C. We performed a regression analysis to test for correlation between fat thickness and tissue temperature rise of subjects. There was a small positive but insignificant correlation (r=.128). This supports the claim of Grotthus and Draper. Since subcutaneous fat does not serve as a barrier to therapeutic ultrasound, athletic trainers and physical therapists can expect comparable increases in muscle temperature when using this modality on people with varying thicknesses of adipose tissue.*

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Therapeutic ultrasound has been used for healing wounds,[2,5-8,10,18] relieving pain,[15,20] eliminating calcium deposits,[4] increasing tendon extensibility,[2,16] treating plantar warts,[3,11,16,17,19] decreasing joint stiffness, reducing muscle spasms, and increasing blood flow.[16] Ultrasound is often preferred over other thermal modalities, due to its greater depth of penetration. Most heating modalities, such as whirlpool, paraffin, and hot packs, heat the tissues to about 1-cm deep.[1,15,16] Ultrasound and diathermy have a depth of penetration up to 5 cm.[16] This depth of penetration is extremely beneficial when dealing with a multitude of sport and recreational injuries.

The Law of Grotthus-Draper describes tissue effects on ultrasound energy.[9,14,16] In accordance with the law, ultrasound: 1) penetrates through tissues high in water content, 2) is absorbed in tissues high in protein, 3) reflects off bone, and 4) refracts through joints. Due to the properties of fat, ultrasound will penetrate it easily and focus energy on muscle, where the sound is absorbed. We have not found any *in vivo* studies performed on humans in which ultrasound's ability to heat tissues through various thicknesses of fat was investigated. The purpose of our study was to measure tissue temperature at 3-cm depth during ultrasound treatments on humans of various skinfold thicknesses in the lower leg.

Methods

Procedures for this study were approved by the university's Human Subject Research Board. In all, 20 males (age=23±2.2 yr) participated in the study. The subjects' mean calf skinfold was 12.6±6.1 mm, with a range of 4 to 30 mm.

In order to determine how much fat existed between the skin surface and our target tissue (3-cm depth), we measured skinfold thicknesses of the belly of the calf with a caliper (Slimguide, Creative Health Products, Plymouth, Mich). Since the skinfold consisted of two thicknesses of fat, we divided each subject's skinfold by two. This gave us the thickness of the layer of fat and skin between the ultrasound head and the muscle. We subtracted this figure from 3 cm to determine how deep in the muscle the thermistor was. For example, if a subject had a skinfold thickness of 1 cm, 0.5 cm of this was one layer of fat. The needle was 3-cm deep into the tissue, so 3 cm - 0.5 cm = 2.5 cm of muscle thickness.

Since the experiment included inserting a heat-sensitive thermistor, we put subjects on an antibiotic therapy program 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 at 6-hour intervals.

A 10-cm-diameter area on the center of the belly of the right medial gastrocnemius of each subject served as the treatment target. We shaved this area and cleansed it with Betadine scrub and 70% isopropyl alcohol. A physician anesthetized the skin with a subcutaneous

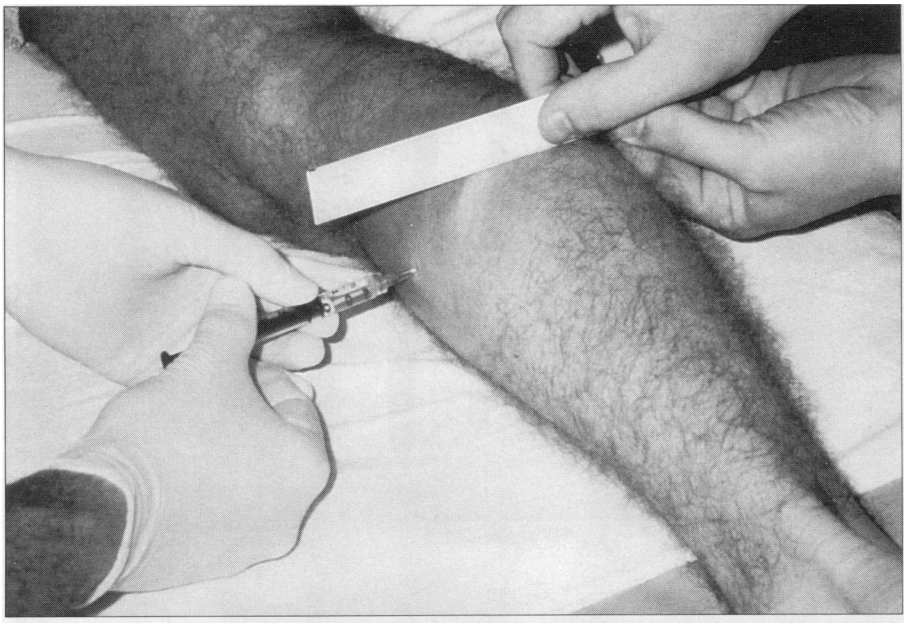

Fig 1.—Prior to the insertion of the needle microprobe, a physician anesthetized the area with an injection of 0.5 cc of lidocaine (Xylocaine). It was through this hole that the thermistor was inserted.

injection of 0.5 cc of 1% lidocaine (Xylocaine) (Fig 1).

A physician inserted a 23-gauge hypodermic needle microprobe into the belly of the right medial gastrocnemius muscle while the subject lay prone. Since we wanted to measure muscle temperature, the probe was inserted 3-cm deep, well below the depth of subcutaneous fat. The distance from the soundhead to the thermistor tip was 3 cm. This needle thermistor was connected to a digital monitor, which displayed the temperature in °C.

We applied 15 ml of 37°C ultrasound gel to the treatment area. After the intertissue temperature reached a baseline, we began the ultrasound treatment. We used the Sonicator 706 (Mettler Electronics, Anaheim, Calif) for ultrasound treatments. The generator operates at a frequency of 1.0 MHz. The 5-cm-diameter transducer houses a barium titanate crystal. We used continuous ultrasound at an intensity of 1.5 W/cm^2. We moved the sound head along the skin in a longitudinal overlapping manner at a speed of 4 cm/s (Fig 2). These strokes were three to four times the size of the soundhead in an area 10 cm in diameter. We recorded the temperature to the nearest 0.1°C every 30 seconds for 10 minutes, or until there was no temperature increase on three consecutive readings. After we completed the 10-minute ultrasound treatment, a nurse removed the thermistor. No complications or infections occurred to the subjects from this study.

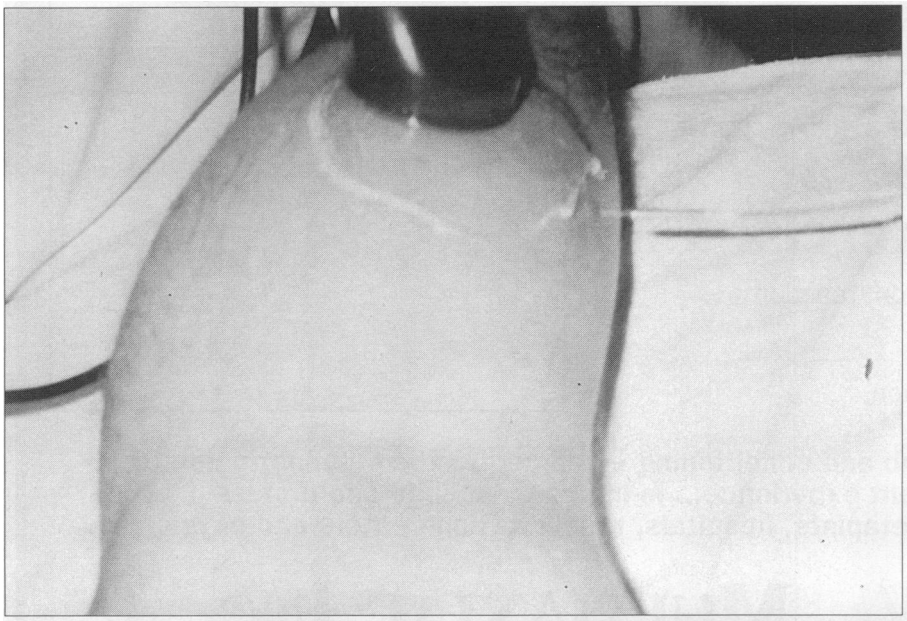

Fig 2.—Application of ultrasound showing the needle microprobe inserted in the medial gastrocnemius at 3-cm depth.

Results

The average baseline temperature was 35.4±1.2°C and the mean temperature plateau was 40.3±1.63°C, which was a muscle temperature increase of 4.9±1.43°C.

Because of the nature of this study, we used two statistical procedures to assess the data. First, we performed an analysis of variance to see if there was a temperature difference between two groups; those with <10 mm of subcutaneous fat and those with >10 mm of subcutaneous fat in the calf (n=10 for each group). Subjects with <10mm had an average temperature increase of 4.9±1.0°C, while those with skinfolds >10 mm recorded mean temperatures of 4.8±1.7°C, a nonsignificant difference ($F(1,18)=.96$, $p=.34$).

Since the range in skinfolds was fairly large (4 mm to 30 mm;X=12.6± 6.1 mm), we also performed a regression analysis to determine if there was a relationship between the amount of subcutaneous fat and tissue temperature rise in the leg. There was a small, positive correlation ($r=.128$) which was not significant ($F(1,19)=.32$, $p=.58$).

Discussion

Many thermal agents are available for treating athletic injuries. Generally these fall into two groups: superficial or infrared agents, and deep-heating agents. Infrared agents frequently used in athletic training are: Hydrocollator

packs, paraffin baths, and whirlpools. It is generally believed that no form of infrared energy can penetrate greater than 1 cm into tissue.[1] One possible explanation for this is that superficial fat serves as a barrier to this energy.[12,13] When selective heating of deep tissue is desired, the modality of choice is ultrasound.

The ability for ultrasound to penetrate through fat has been tested using laboratory animals. Lehmann and colleagues[13] used a thermistor system much like ours to measure temperatures in various structures of the knee joints of pigs. They reported that the highest temperatures occurred in the superficial bone and in the meniscus. The next highest temperatures were in the joint capsule, while the lowest temperatures were recorded in the overlying soft tissues, especially the fat.

Lehmann and coworkers[12] also measured the effects of ultrasound on temperature elevation in humans, using a thermistor system. Each subject received two treatments, one at 1.0 W/cm^2 and the other at 1.5 W/cm^2. Treatments lasted 15 minutes, or until the subject complained of pain. In subjects with 8 cm of soft tissue thickness from the skin to the bone, the temperature increased as the intensity of the ultrasound unit was increased. We have shown, like Lehmann and associates,[12,13] that ultrasound can penetrate through subcutaneous tissues, including fat. Yet, we have extended their work by comparing the tissue temperature increases in subjects with varying thicknesses of fat. Based upon the results of our study, we believe that 1 MHz ultrasound is absorbed little in superficial tissues and will penetrate equally through various thicknesses of subcutaneous fat.

The results of this study support the postulation of Grotthus and Draper[9,14,16] and have merit for anyone involved in using therapeutic ultrasound for increasing the temperature of muscle tissue up to 3-cm deep. Since fat serves as a barrier to superficial heating agents, whirlpool, paraffin, and hot packs are not effective in causing deep tissue temperature increases, especially in subjects with much adipose tissue.[1,15,16] We conclude that athletic trainers and physical therapists can use ultrasound to treat

deep injuries in athletes or patients with varying thicknesses of adipose tissue.

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