ULTRASONIC is often used in athletic training as a deep-heating therapeutic modality.\(^1\)\(^-\)\(^5\) It is used for a variety of reasons, including pain control,\(^6\) wound healing,\(^7\) drug delivery,\(^8\) stretching collagenous tissue,\(^9\) reduction of muscle spasms,\(^10\) and trigger point release.\(^11\)\(^,\)\(^12\) The most common conditions that are treated with ultrasound include acute and chronic inflammatory conditions, sympathetic nervous disorders, and post-acute resolution of myositis ossificans.\(^11\)\(^,\)\(^12\) However, evidence of its effectiveness for treatment of most musculoskeletal conditions is limited. The current body of knowledge about ultrasound application primarily relates to the rate and magnitude of tissue heating at a given depth beneath the body surface. The purposes of this report are to clarify research findings about the variability among ultrasound devices and to provide guidance for selection of appropriate parameters for administration of treatments.

The thermal effect of ultrasound is often related to three categories of heating: mild (1°C), moderate (2-3°C), and vigorous (>4°C). Mild heating is believed to decrease sub-acute inflammation and to accelerate the metabolic rate. Moderate heating is suggested for treatment of chronic inflammation, pain, and muscle spasm, and to increase blood flow. Vigorous heating is necessary to increase the extensibility of collagen and joint ROM.\(^12\)\(^,\)\(^13\) The heating effect depends greatly on the treatment parameters used, the tissues being treated, and the device used to deliver the treatment.

The treatment parameters used to produce mild to vigorous heating of tissues have been presented in great detail in the literature. There seems to be a consensus regarding the parameters that should be used for creation of thermal effects in muscle tissue, but there is inconsistency in the magnitude of thermal effect produced by different ultrasound devices at the same energy output settings.\(^5\)\(^,\)\(^14\) Johns et al.\(^15\)\(^,\)\(^16\) have demonstrated that heating effect varies among units produced by the same manufacturer. Demchak et al.\(^17\) recently reported that the rate of heating is not as linear as once thought and that it varies between transducers produced by the same manufacturer. These findings.
present several nagging questions. How does a clinician know that all ultrasound units are heating tissue at comparable rates? Are all similarly manufactured ultrasound units producing the same heating effect at a given power setting? The treatment parameters recommended by Draper et al. appear to be appropriate to achieve the effects of mild (1°), moderate (2-3°), and vigorous (<4°) heating within muscle tissue, but there is doubt about the effect that will be produced by different units.

**Variability in Heating**

Many clinicians have assumed that a given power output to the tissues will result in equal heating, regardless of device. Evidence to the contrary was presented in 2003 by Holcomb and Joyce. They compared the Omnisound 3000 and the Forte 400 Combo units in terms of heating effect at 1.2 cm depth below the skin surface. The treatment parameters were 3 MHz frequency and 1.0 W/cm² power output for a treatment area that was double the size of the 5 cm² transducer faceplate. The temperature was measured at 10 minutes or when the tissue temperature reached 6 degrees above baseline. A significantly greater heating effect was produced by the Omnisound 3000 (5.81 ± 0.41°C) compared to that of the Forte 400 Combo (3.85 ± 0.75°C).

Merrick et al. performed a comparable study that involved temperature measurement at a tissue depth of 1.6 cm beneath the skin surface for the Omnisound 3000, Dynatron 950, and Excel Ultra III units. The treatment parameters were 3 MHz frequency and 1.5 W/cm² power output for a treatment area that was double the size of the 5 cm² transducer faceplate. The temperature was measured at 6 minutes and at the end of the 10-minute treatment. The Omnisound 3000 produced significantly greater heating at 6 minutes (>6°C). The treatment was discontinued at 6 minutes because each subject began to experience discomfort at a temperature of 41°C. The Dynatron 950 and the Excel Ultra III units did not produce a 40°C average tissue temperature. The Omnisound 3000 differed from the Dynatron 950 and the Excel Ultra III, but the Dynatron and the Excel did not differ from each other. One the basis of these findings, there appears to be a difference in the performance of ultrasound devices.

Assuming that the heating rate reported by Draper et al. for the Omnisound ultrasound device is accurate for other units, one can predict the temperature increase within tissues for a given set of treatment parameters. The tissue temperature increase at 10 minutes would be approximately 6°C (0.58°/min) for the 3 MHz, 1.0 W/cm² treatment used by Holcomb and Joyce, and the tissue temperature increase would be approximately 6°C in 6 min (0.96°/min) for the 3 MHz, 1.5 W/cm² treatment used by Merrick et al. These tissue temperature predictions are correct for the Omnisound 5000 device, but the reported values for other units are lower than the predicted values. Apparently, the Forte 400 Combo, the Dynatron 950, and the Excel Ultra III heat the tissue in a less effective manner.

To understand the reason that various ultrasound units perform differently, one must consider the mechanism by which ultrasound generates heat within the tissues. There are several factors that need to be taken into consideration, including the effective radiating area (ERA) and energy intensity. The energy intensity is determined in several ways, including the spatial average intensity (SAI), the spatial average temporal peak (SATP), and the spatial average temporal average (SATA). This report will focus on the SAI, because the SATP and SATA are only relevant when using ultrasound with a duty cycle less than 100%, which is not typically used for generation of a thermal effect.

To maximize treatment effectiveness, one must determine the treatment area in relation to the ERA of the ultrasound head. The ERA is the area to which energy is conducted, which is somewhat smaller than the size of the sound head. Energy intensity is represented by W/cm², which is the rate at which energy is delivered per unit of area. SAI is determined by dividing the power (W) by the ERA (cm²), which is represented in units of W/cm². The SAI and duration of treatment determine amount of energy that is transmitted to the tissues. The beam non-uniformity ratio (BNR) is a representation of the homogeneity of energy transmission beneath the ultrasound head, which may be responsible for the variability in heating effect between devices. The BNR is the ratio of the spatial peak intensity to the SAI.

Most ultrasound units will deliver energy at frequencies of 1 MHz or 3 MHz. The 3 MHz frequency is used to heat superficial structures, such as the patellar tendon, whereas the 1 MHz frequency is used to heat deeper structures, such as the quadriceps. Low-frequency ultrasound (1 MHz) will increase tissue temperature at a slower rate than high-frequency ultrasound (3 MHz) when delivered at the same level of power output. A