Effect of Continuous-Wave Ultrasound on Blood Flow in Skeletal Muscle

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Background and Purpose. *The purpose of this study was to determine the effect of ultrasound on forearm, skin, and muscle blood flow.* ***Subjects.*** *Twenty volunteers without known vascular problems (10 male, 10 female) participated.* ***Methods.*** *All subjects received a treatment of continuous-wave ultrasound to the anterior forearm at a dosage of 1.5 W/cm² for a duration of 5 minutes. The contralateral forearm served as the control and received identical treatment, except the ultrasound output remained at zero. Forearm blood flow was measured using venous occlusion plethysmography, and skin blood flow was measured using cutaneous laser-Doppler flowmetry before and after ultrasound administration, with the difference being muscle blood flow.* ***Results.*** *No differences between the control arm and the ultrasound-treated arm were found for muscle, skin, and forearm blood flow.* ***Conclusion and Discussion.*** *These results suggest that administration of continuous-wave ultrasound at the prescribed dosage had no effect on skeletal muscle blood flow for up to 30 minutes posttreatment. Thus, muscle hyperemia is probably not the primary mechanism responsible for the clinical benefits seen following the use of ultrasound as a therapeutic modality. [Robinson SE, Buono MJ. Effect of continuous-wave ultrasound on blood flow in skeletal muscle. Phys Ther. 1995;75:145–150.]*

Key Words: *Cutaneous laser Doppler, Muscle blood flow, Muscle hyperemia, Skin blood flow, Ultrasound, Venous occlusion plethysmography.*

Physiological and therapeutic properties of ultrasound are attributed to thermal and various nonthermal reactions.[1–5] The tissue responses to the thermal effects of ultrasound include increased tissue metabolism, increased permeability of biological membranes, and changed membrane potentials.[3,5–7] One of the proposed effects of ultrasound is that it increases blood flow to skeletal muscle.[7–10] We believe this supposition is generally accepted throughout the physical therapy and athletic training communities, despite a lack of scientific evidence to substantiate this claim. An informal telephone survey of 20 physical therapists and 5 certified athletic trainers revealed a 100% affirmative response to the question, "Does ultrasound diathermy increase blood flow to skeletal muscle?"

Most studies attempting to quantify blood flow changes following ultrasound treatment have measured the total limb blood flow without separating cutaneous and muscle flow.[7–10] The works of Paul and Imig,[7] Abramson et al,[8] and Bickford and Duff[10] all involved the use of venous occlusion plethysmography to determine total limb blood flow following the administration of ultrasound. The increases

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in limb blood flow observed in these studies were attributed to increased muscle blood flow. More recent studies,[11–13] however, using local xenon-133 washout techniques, have concluded that ultrasound did not increase subcutaneous or muscle blood flow in healthy subjects. The purpose of our study was to determine changes in muscle blood flow in the human forearm after application of a commonly prescribed dosage of ultrasound. The method used to determine muscle blood flow was to examine the difference between total forearm blood flow and measured skin blood flow.[14]

Method

Subjects

Twenty volunteers (10 men and 10 women), ranging in age from 22 to 56 years ($\bar{X}$=29, SD=8), participated in the study. All subjects had normal sensation in the upper extremities. Only healthy subjects, without known pathology (eg, peripheral vascular disease), were used to eliminate the effect of such clinical conditions on blood flow. All subjects gave written informed consent prior to participation.

Instrumentation

Forearm blood flow was measured using a strain-gauge plethysmograph according to the procedure outlined by Tripathi and Nadel.[14] A double-stranded mercury-in-Silastic* strain gauge, which was 2 cm smaller than the measured circumference of the proximal forearm, was placed around the forearm at the point of greatest girth and attached to a Hokanson model EC-5 plethysmograph.† The position of the strain gauge was marked with indelible ink for future reference. An inflatable cuff was attached just proximal to the elbow and connected to an electric pneumatic pump preset to an inflation pressure of 50 mm Hg. At this pressure, venous outflow is occluded; however, arterial inflow is unimpeded, causing increased blood volume in the forearm. The mean time to maximal inflation was 2.5 seconds. A smaller cuff was applied to the distal forearm at the wrist crease and inflated manually to 220 mm Hg prior to the application of the proximal venous occlusion. At this pressure, blood flow into and out of the hand was occluded, thus isolating the forearm segment for study.

Skin blood flow measurements were obtained with a TSI LASERFLO model 403A blood perfusion monitor.‡ A proximal probe head was secured to the anterior forearm at the midline, 5 cm distal to the strain gauge. A second probe head was placed 5 cm distal to the first probe head over the anterior forearm and also at midline. Again, the placements were marked with indelible ink for future reference. The probe head, attached to a fiber-optic cable, directs laser light into the tissue, illuminating a volume containing both stationary tissue and red blood cells. Photons scattered by the moving red blood cells are Doppler shifted. The scattered light is collected by return fibers in the cable, which are connected to a photo detector in the blood perfusion monitor. By converting the light into electronic signals, the blood perfusion monitor produces outputs proportional to cutaneous blood flow. The use of laser-Doppler flowmetry to quantify cutaneous blood flow has been supported in the literature.[15–22] The Figure illustrates the experimental setup.

Procedure

All procedures were explained to the subjects prior to the start of the testing session. The procedure for the control arm was identical to that for the treatment arm, except the ultrasound machine was not turned on. The forearm was prepared, and each subject rested in the supine position with the arm at approximately the level of the heart for 5 minutes prior to obtaining resting values from the cutaneous flow monitor and the plethysmograph. Immediately after obtaining the pretreatment values, the strain gauge and cutaneous laser probe heads were removed. The anterior forearm was treated with continuous-mode ultrasound at a dosage of 1.5 W/cm^2 for a duration of 5 minutes. A Chattanooga Corporation Intellect 205 portable ultrasonicator,§ at a frequency of 1.0 MHz, was used to deliver the ultrasound with a 5-cm sound head over an area visually estimated to be 25% of the total forearm surface (approximately 80–125 cm^2). The instrument was calibrated using standard procedures immediately prior to initiation of the study by a US Navy certified electronic/medical technician. Aquasonic 100 ultrasound gel‖ was used as the coupling medium. At the end of the 5-minute treatment, the forearm preparation was repeated. The previously marked locations of the probe heads and strain gauge allowed for exact replacement. The time from cessation of treatment to commencement of the initial posttreatment reading was 2 minutes.

Cutaneous flow measurements were obtained by recording from the proximal head first and then from the distal head, using the average of the two recordings as the skin blood flow value. Pilot testing in our laboratory (n=5) revealed that the same-day test-retest intraclass correlation coefficient (ICC[1,1]) for this procedure was R=.91. After monitoring cutaneous flow, the distal arm cuff was inflated to 220 mg Hg and the proximal cuff was inflated to 50 mm Hg. Two consecutive readings were obtained from the plethysmograph, and again the mean value represented the total forearm

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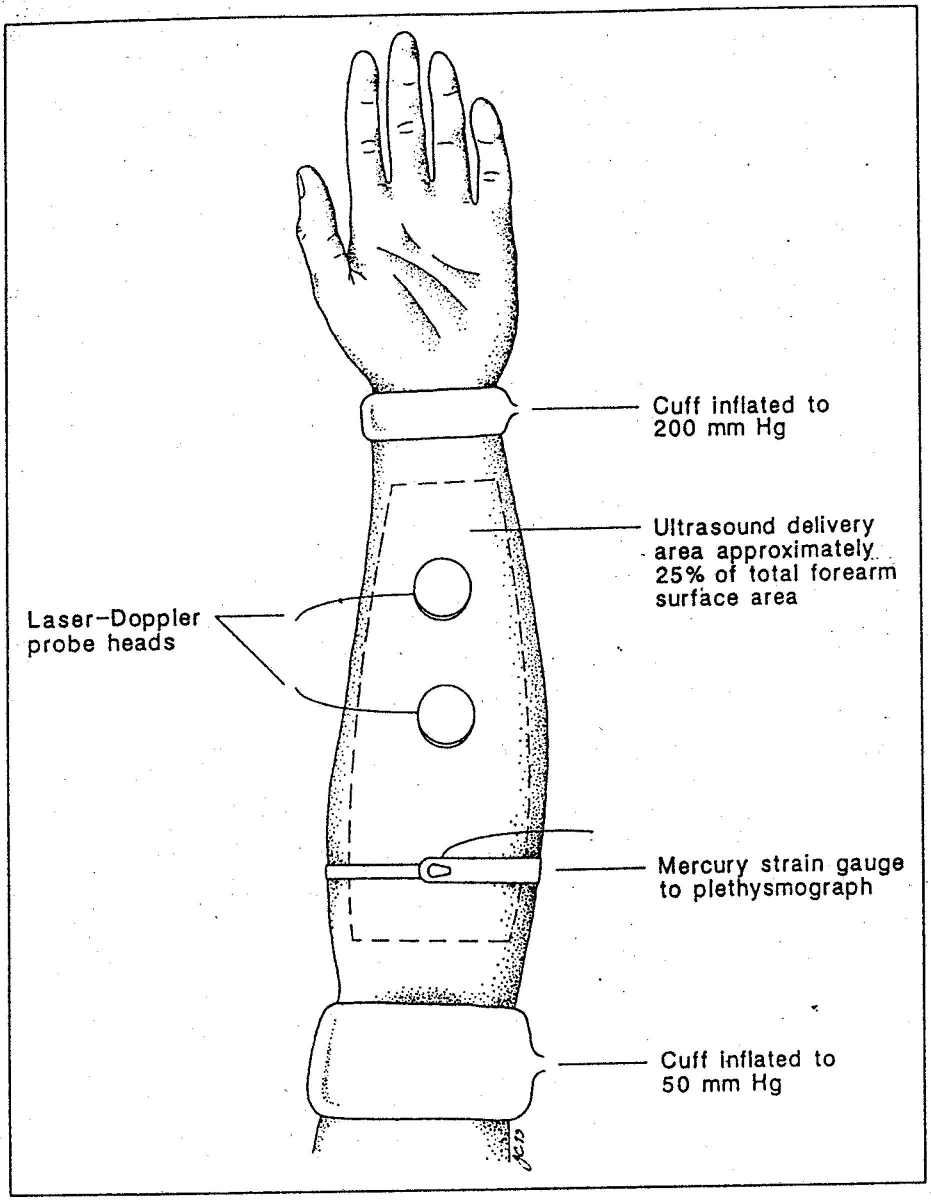

Figure. *Illustration of experimental setup.*

volume change. After the second reading, the pressure cuffs were deflated. The same-day test-retest ICC for this procedure in our laboratory (n=5) was R=.85. This recording procedure was repeated at 5-minute intervals for 30 minutes following treatment.

Because the cutaneous flow was monitored with the probe head placed only over the treatment areas, the total value reported had to be determined on a proportional basis. Forearm surface area measurements showed that the treated area comprised only 25% of the total; thus, this area represented only one fourth of the total forearm cutaneous flow. The remaining 75% was assumed to stay at the resting level. This assumption was confirmed from a pilot study on five individuals in which resting cutaneous blood flow, as monitored with sensors over both the anterior and posterior surfaces of the forearm, resulting in no difference between the two recording sites. In addition, cutaneous flow recordings were taken from the posterior sites, during and after administration of an ultrasound treatment to the anterior forearm. Again, no difference was noted in comparison with the resting values. Therefore, the skin blood flow was defined as the sum of 75% of the resting value and 25% of the posttreatment value. Muscle blood flow was calculated as the difference between forearm blood flow and skin blood flow. Similar methodology has previously been used to determine muscle blood flow during lower-body negative pressure.[14]

Data Analysis

A two-factor (condition and time) repeated-measures ANOVA and Tukey's *post hoc* test were used to provide statistical measurement on total forearm blood flow, skin blood flow, and muscle blood flow. Significance was set at the $P<.05$ level unless otherwise noted. All values were expressed as means ± standard deviation.

Results

The mean (±SD) muscle, skin, and forearm blood flow for both control and ultrasound arms are shown in the Table. Results of the three ANOVAs indicated that muscle, skin, and forearm blood flow was not significantly different between the control and ultrasound-treated arms. A significant time effect, however, was found for skin and forearm blood flow. *Post hoc* comparisons of pretreatment versus posttreatment values indicated that skin blood flow was significantly increased through 15 minutes, whereas forearm blood flow was significantly increased through 5 minutes. No significant time effect was found for muscle blood flow.

Discussion

Eight previous investigations studying the effect of ultrasound diathermy on blood flow have been reported.[7–13,23] Four studies[7–10] indicated that ultrasound, depending on the dosage and duration of application, may be beneficial in augmenting tissue blood flow. These four studies reported increases in total forearm blood flow of approximately 25% or greater using plethysmography. This value agrees quite favorably with the mean 23% increase in total forearm blood flow found in our study following ultrasound treat-

[redacted]

Table. *Mean Forearm, Skin, and Muscle Blood Flow in Ultrasound-Treated and Control Arms Before and After Treatment*[a]

	Time (Minutes Posttreatment)							
	Pretreatment	2	5	10	15	20	25	30
Forearm blood flow								
Ultrasound	4.8±2.2	5.9±3.1	5.8±2.2	5.2±2.6	5.1±2.2	5.2±2.2	4.9±2.2	5.0±2.2
Control	4.6±2.2	5.2±2.6	5.5±2.6	5.4±3.1	4.8±2.2	4.7±2.2	4.7±2.2	4.6±2.2
Skin blood flow								
Ultrasound	2.0±0.9	3.1±1.8	2.8±1.3	2.6±1.8	2.5±1.3	2.4±1.3	2.2±1.8	2.2±1.3
Control	2.1±0.9	3.3±2.2	2.9±1.8	2.9±1.8	2.7±1.3	2.6±0.9	2.5±0.9	2.5±0.9
Muscle blood flow								
Ultrasound	2.8±2.2	2.8±3.1	2.9±2.2	2.6±2.2	2.7±2.2	2.9±2.2	2.6±2.2	2.8±1.8
Control	2.4±1.8	1.8±2.2	2.5±1.8	2.4±1.8	2.1±1.8	2.0±1.8	2.2±1.8	2.1±1.8

[a] All values are means±standard deviation and are expressed in milliliters per 100 milliliters per minute.

ment (Table). The similarity of these findings supports the hypothesis that the investigators in the previous studies did find increases in total forearm blood flow following ultrasound treatment. Their assumption, however, that increased flow was specific to muscle seems unwarranted. The investigators in the remaining four studies,[11–13,23] concentrating specifically on blood flow changes in muscle, concluded that ultrasound had no effect. The present research suggests that a clinical dosage of ultrasound did not enhance muscle blood flow; however, total forearm blood flow was augmented via significant increases in skin blood flow. The fact that skin and total forearm blood flow also increased in the control arm suggests that the massaging action of the ultrasound head may be responsible for these effects.

The seemingly conflicting results of the previous studies may be explained in several ways. All the prior studies that showed an improvement in blood flow following ultrasound treatment used plethysmography to measure total limb volume changes. Although plethysmographic measurements have demonstrated reliability for this purpose, they do not reflect isolated flow changes in specific tissues. Bickford and Duff[10] reported that ultrasound irradiation at "tolerable intensities" was not an effective means of causing a prolonged increase in blood flow. In spite of this finding, their study is frequently referenced as one supporting the view that therapeutic dosages of ultrasound increase muscle blood flow. They surmised that when the intensity was sufficient to elevate total forearm blood flow, the increase was in the muscle, secondary to a local thermogenic effect. In view of more recent evidence, this assumption must be questioned. Furthermore, it should also be noted that Bickford and Duff[10] lacked convincing statistical évidence to support any of their findings.

Paul and Imig[7] also noted changes in total blood flow only when intensities exceeded tolerable limits. They made no direct inference, however, of increased flow specifically to muscle tissue. Abramson et al[8] reported increased blood flow using pulsed-mode ultrasound, with augmentation extending to 26 minutes posttreatment. They reported the greatest temperature increases in the subcutaneous tissue, versus muscle, thus inferring the increased flow was primarily in the subcutaneous tissue. As noted before, however, the plethysmographic method of measurement alone cannot isolate blood flow in a specific target tissue. In a similar fashion, Baker and Bell[9] used impedance plethysmography to demonstrate increased total blood volume after ultrasound treatment. Their suggestion that ultrasound may increase blood flow in muscle, and referencing the Bickford and Duff study[10] to support their conclusion, is questionable.

The four studies[11–13,23] that demonstrated that ultrasound did not increase blood flow in muscle were designed specifically to examine effects in muscle tissue. Three of the projects[11–13] used the xenon-133 wash-out technique, which has been validated. In the fourth study, Rubin et al[23] performed a series of experiments on rats, using a red blood cell velocity correlator system to examine flow at the muscle arteriolar level. The results of all of these studies agree with our findings and suggest that ultrasound does not increase muscle blood flow.

One limitation of our work was our inability to monitor blood flow during the actual ultrasound treatment. Because of this limitation, any increases that occurred during the ultrasound treatment were missed. If the primary goal of treatment, however, is to elevate blood flow in muscle tissue and maintain that level for a prolonged period, this limitation does not appear relevant.

Conclusion

Based on the results of our research, continuous-wave ultrasound administered at a commonly prescribed dosage and duration had no effect on blood flow to skeletal muscle during the 30-minute posttreatment period. These results agree with the published studies that have used measurement techniques designed to examine changes specifically in muscle. Previous researchers who have suggested that increases in muscle blood flow occur following ultrasound treatment used the plethysmographic measurement method exclusively. This method alone, however, cannot be used to differentiate flow between the various tissues; therefore, those authors' opinions concerning muscle blood flow are pure conjecture.

Lastly, the results of our study in no way suggest that ultrasound is without clinical benefit. The results of our study do, however, suggest that muscle hyperemia is probably not the primary mechanism of action.

References

1 Duarte LR. The stimulation of bone growth by ultrasound. *Arch Orthop Trauma Surg.* 1983;101:153–159.

2 Dyson M, Brooks M. Stimulation of bone repair by ultrasound. *Ultrasound Med Biol.* 1982;8:61–66.

3 Dyson M, Suckling J. Stimulation of tissue repair by ultrasound: a survey of mechanisms involved. *Physiotherapy.* 1978;64:105–108.

4 Frieder S, Weisberg J, Fleming B, Stanek A. A pilot study: the therapeutic effect of ultrasound following partial rupture of Achilles tendons in male rats. *J Orthop Sports Phys Ther.* 1988;10(2):39–46.

5 Krusen FH, Kottke FJ, Ellwood PM. *Handbook of Physical Medicine and Rehabilitation.* 2nd ed. Philadelphia, Pa: WB Saunders Co; 1971:297–321.

6 Lota MJ. Electronic plethysmography and tissue temperature studies of effect of ultrasound on blood flow. *Arch Phys Med Rehabil.* 1965;46:315–322.

7 Paul WC, Imig CJ. Temperature and blood flow studies after ultrasonic irradiation. *Am J Phys Med.* 1955;34:370–375.

8 Abramson DL, Burnett C, Bell Y, et al. Changes in blood flow, oxygen uptake, and tissue temperatures produced by therapeutic physical agents. *Am J Phys Med.* 1960;38:51–62.

9 Baker FJ, Bell GW. The effect of therapeutic modalities on blood flow in the human calf. *J Orthop Sports Phys Ther.* 1991;13(1):23–27.

10 Bickford RH, Duff RS. Influences of ultrasonic irradiation on temperature and blood flow in the human skeletal muscle. *Circ Res.* 1953;1:534–538.

11 Paaske WP, Hovind H, Sejrsen P. Influence of therapeutic ultrasonic irradiation on blood flow in human cutaneous, subcutaneous, and muscular tissues. *Scand J Clin Lab Invest.* 1973;31:389–394.

12 Hansen TI, Kristensen JH. Effect of massage, shortwave diathermy and ultrasound upon 133Xe disappearance rate from muscle and subcutaneous tissue in the human calf. *Scand J Rehabil Med.* 1973;5:179–182.

13 Wyper DJ, McNiven DR, Donnelly TJ. Therapeutic ultrasound and muscle blood flow. *Physiotherapy.* 1978;64:321–322.

14 Tripathi A, Nadel ER. Forearm skin and muscle vasoconstriction during lower body negative pressure. *J Appl Physiol.* 1986;60:1535–1541.

15 Haberl RL, Heizer ML, Marmarou A, Ellis EF. Laser-Doppler assessment of brain microcirculation: effect of systemic alterations. *Am J Physiol.* 1989;256(Heart Circ Physiol 25):H1247–H1254.

16 Hassan AK, Rayman G, Tooke JE. Effect of indirect heating on the postural control of skin blood flow in the human foot. *Clin Sci.* 1986;70:577–582.

17 Rendell M, Bergman T, O'Donnell G, et al. Microvascular blood volume and velocity measured by laser-Doppler techniques in IDDM. *Diabetes.* 1989;38:819–822.

18 Saumet JL, Kellogg DL Jr, Taylor WF, Johnson JM. Cutaneous laser-Doppler flowmetry: influence of underlying muscle blood flow. *Am J Physiol.* 1988;65:478–481.

19 Smits GJ, Roman RJ, Lombard JH. Evaluation of laser-Doppler flowmetry as a measure of tissue blood flow. *J Appl Physiol.* 1986;61:666–672.

20 Joyner MJ, Lennon RL, Wedel DJ. Blood flow to contracting human muscles: influence of increased sympathetic activity. *J Appl Physiol.* 1990;68:1453–1457.

21 Sundberg S. Acute effects and long-term variations in skin blood flow measured with laser-Doppler flowmetry. *Scand J Clin Lab Invest.* 1984;44:341–345.

22 Taylor WF, Johnson JM, Kosiba WA, Kwan CM. Graded cutaneous vascular responses to dynamic leg exercise. *J Appl Physiol.* 1988;64:1803–1809.

23 Rubin MJ, Etchison MR, Condra KA, et al. Acute effects of ultrasound on skeletal muscle oxygen tension, blood flow, and capillary density. *Ultrasound Med Biol.* 1990;16:271–277.