Influence of Ultrasonic Irradiation on Temperature and Blood Flow in Human Skeletal Muscle

By Robert H. Bickford, M.D., and Robert S. Duff, M.D.

The circulatory response to ultrasonic irradiation of the upper limbs was measured under controlled conditions by venous occlusion plethysmography. Volumetric blood flow changes were related to temperature measurements in the treated tissues. Ultrasonic irradiation of the extremities was not found, per se, to be an effective means of promoting a sustained increase in blood flow. The information obtained on the nature of the circulatory effects of ultrasonation permits a more satisfactory evaluation of this new method of treatment.

In recent years ultrasonic irradiation has been employed, especially in Europe, for the treatment of painful, inflammatory and ischemic disorders of the extremities.1 There appears, however, to be little direct information on the precise physiologic changes in tissues subjected to ultrasonic therapy. It is known that excessive ultrasonation may produce harmful effects in experimental animals.2 We have, therefore, investigated the effects of different intensities of ultrasonic irradiation on the temperature and blood flow of muscular segments of the upper limbs of man.

Technic

The subjects were 20 men and 6 women between the ages of 16 and 61 years. All but three were normotensive and none had clinical evidence of organic occlusive vascular disease. Throughout the whole period of observation each subject was seated comfortably in a laboratory in which the temperature remained fairly steady, never fluctuating more than 1°C. The mean temperature of the air near the subject and the oral temperature were recorded every 5 to 10 minutes.

An ultrasonic generator (Siemens "Sonostat" Universal Ultrasonic Generator) capable of delivering from 0.2 watts per square centimeter to 5.3 watts per square centimeter at a frequency of 800 kilocycles was employed. The applicator, which has a water-cooled plane surface of 10 cm., was applied to successive areas of the skin covering the segments of limbs selected for study, with mineral oil as the contact medium. The delineated area was confined to the most muscular portion of the forearm from the olecranon to about 10 cm. above the wrist. The applicator was gently moved, with slight pressure, over the entire skin surface of this segment in repeated regular cycles during the period of treatment so as to favor an even distribution of the ultrasonic energy.

Blood flow was estimated by venous occlusion plethysmography, employing plastic plethysmographs filled with water at a steady temperature.3,4 We adopted a technic5 which enabled the instrument to be rapidly applied to and removed from the forearm. This permitted us to measure the forearm blood flow before and within three to five minutes following ultrasonic applications. In addition to the customary volume recorder, volumetric changes were evaluated in terms of pressure differences detected by a Statham Strain Gauge, recorded by a Brush electromagnetic analyzer.

Temperature changes were measured by iron-constantan thermocouples housed in hypodermic needles inserted into the tissues of the forearm at specified depths.6 These changes were recorded by a Leeds Northrup potentiometer, standardized against a Bureau of Standards thermometer. Temperatures were recorded from the skin and subcutaneous tissue, and from the muscles at depths of 1.5 and 3.0 cm.

The general procedure consisted of making repeated observations (of forearm blood flow or temperature or both) at approximately half-minute intervals during a 20-minute control period at the end of which the measuring apparatus was rapidly removed. For the next 15 minutes the specified treatment was applied to the forearm, and as soon as possible thereafter (three to five minutes) the apparatus was reapplied under conditions identical to...
those during the control period. Repeated observations were then resumed for a further 20 minutes.

Results

I. Control study of effect on forearm blood flow of massaging the skin with the ultrasonic applicator. In four individuals the forearm blood flow was first measured during a 20-minute resting period, using a plethysmograph filled with water at 35 ± 1.0°C. This was removed and during the next 15 minutes the ultrasonic applicator was moved over the forearm skin in a manner identical to that of a regular ultrasonic treatment except that the ultrasonic generator was not switched on. The subjects, who were familiar with the apparatus, were encouraged to believe a regular ultrasonic application was being given.

TABLE 1.—Forearm Blood Flow before and after 15 minutes Massage with Ultrasonic Applicator, without Irradiation.

<table>
<thead>
<tr>
<th>Age of Subject Years</th>
<th>Room Temp. °C</th>
<th>Plethysmograph Temp. °C</th>
<th>Forearm Blood Flow ml/100 ml./min.</th>
<th>Percentage Change in Blood Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>25.0</td>
<td>35.0</td>
<td>2.2</td>
<td>2.2</td>
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<td>27</td>
<td>28.0</td>
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<td>50</td>
<td>25.5</td>
<td>35.4</td>
<td>4.1</td>
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<tr>
<td>37</td>
<td>25.5</td>
<td>35.0</td>
<td>2.4</td>
<td>2.6</td>
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<tr>
<td>Averages</td>
<td></td>
<td></td>
<td>3.0</td>
<td>2.8</td>
</tr>
</tbody>
</table>

At the end of this period the plethysmograph was rapidly reapplied and filled with water at the same temperature as before, and observations of blood flow obtained for 15 to 20 minutes.

In no instance did we find a significant difference in blood flow during the two periods of observation (table 1). This finding was considered to support the assumption in the subsequent studies, in which ultrasonic irradiation was given, that any observed changes in forearm blood flow could not be attributed to the massaging effect of the applicator or to the disturbance of reapplying the plethysmograph.

II. Effect of therapeutic intensities of ultrasonic irradiation on forearm blood flow. Under conditions identical to those of the initial control study the effects of ultrasonic irradiation of 2.0 watts per square centimeter were studied in 18 limbs of 14 subjects. In nine instances the forearm blood flow following ultrasonics was more than 25 per cent greater than the resting blood flow; in six there was little change, and in the remaining three a slight reduction in flow occurred. These results are summarized in table 2. It is evident that, for the group, the blood flow recorded in forearms within three to five minutes following exposure to ultrasonic therapy was not significantly different from that recorded before exposure. We could therefore infer that in about half the subjects ultrasonic irradiation of the forearm in the dosage employed either did not affect the volumetric blood flow through the forearm or caused changes that disappeared within three to five minutes.

III. Effect of increased ultrasonic intensities on forearm blood flow. The forearms of five subjects were exposed to ultrasonic irradiation of 3.0 to 3.5 watts per square centimeter. This intensity was found to be the limit of tolerance of almost every subject, beyond which progressively severe and continuous deep boring
pain occurred. The forearm blood flow changes were measured plethysmographically before and after a 10 to 15 minute application.

As shown in table 3a an appreciable increase in flow (more than 25 per cent) was recorded in four of the five cases, the average flow rising from 3.0 ml. to 4.3 ml. per 100 ml. per minute. Inasmuch as the treatment was attended by unpleasant local sensations these observations permitted only the inference that intense ultrasound is capable of inducing an increase in blood flow.

IV. Temperature changes in forearm tissues following ultrasonic irradiation. The temperature changes in the skin, subcutaneous tissue and muscles of four forearms exposed to the higher 3.5 watts per square centimeter ultrasonation were recorded (table 3b). It was noteworthy that in every instance the skin became cooler after irradiation, probably because of loss of heat to the water-cooled applicator head. Little change in mean temperature of the subcutaneous tissue was recorded, but in all four subjects a rise in muscle temperature of between 1.1 and 2.8 C. occurred. The subject having the smallest rise in deep muscle temperature also had the smallest increase in forearm blood flow. It must be noted that these tissue temperature changes occurred despite the fact that the water surrounding the limb inside the plethysmograph was maintained constant within 0.5 C. before and after ultrasonation.

Table 4.—Blood Flow in Both Forearms of Subjects before and after Ultrasonic Irradiation of One Forearm.

<table>
<thead>
<tr>
<th>No.</th>
<th>Forearm Blood Flow</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Irradiated Side</td>
<td>Control Side</td>
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<tr>
<td>2</td>
<td>3.4</td>
<td>4.4</td>
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<td>3</td>
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<tr>
<td>13</td>
<td>2.6</td>
<td>2.4</td>
</tr>
<tr>
<td>14</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Ave.</td>
<td>4.3</td>
<td>4.9</td>
</tr>
</tbody>
</table>

* Hypertensive patient

On the basis of these observations we presumed that the increased blood flow in the forearm following exposure to intense ultrasonation was predominantly if not exclusively due to vasodilatation in the muscles. Thus far, however, the evidence did not exclude the possibility that these temperature and circulatory changes in the muscles might be secondary local consequences of more general circulatory changes associated with systemic vasomotor and/or hormonal reactions. Concerning this we made the following observations.

V. Blood flow in both forearms of subjects before and after exposure of one forearm to ultrasonation was measured plethysmographically and the changes were recorded.
sonic irradiation. Repeated plethysmographic observations of the blood flow in both forearms of a group of subjects were made. After a 20 minute control period we subjected one forearm of each individual to ultrasonic irradiation in the usual manner, at the intensity 2.0 watts per square centimeter. Repeated measurements of the blood flow in the untreated forearm were continued throughout the whole period of observation. We found (Table 4) that the changes in blood flow in the untreated forearm during and following ultrasonation of the treated forearm did not change significantly, despite increased flow through the treated forearm.

These findings afford evidence that ultrasonic irradiation induces localized vasodilatation in irradiated tissues, without causing systemic relaxation of vascular calibre. It is therefore reasonable to suppose that such vasodilatation as followed the ultrasonic applications represented a direct action of the ultrasonic energy on the irradiated tissue.

Discussion

From the data presented it seems likely that the technic of administering ultrasonic irradiation exposes the forearm to two opposing influences: (a) the contact cooling of the surface skin and (b) the warming effect of the ultrasonic energy on deeper tissues. Thus when moderate ("therapeutic") intensities of ultrasonation are given, any increase in volumetric flow is related, presumably, to the capacity of the superficial vessels to retain heat and to the physical relationship between these vessels and the water-cooled applicator head. An increase in the ratio of deep tissue penetration to surface contact may be expected to favor an increased blood flow through the forearm as a whole and through the muscles in particular.

Unpublished observations of Imig have shown that the circulatory effect of ultrasonic irradiation is related to its net thermogenic effect in the limbs of dogs. Likewise other forms of irradiation, such as short-wave and microwave diathermy, cause hyperemia of the limbs of dogs only when significant increases in muscle temperature are produced.7 8

In line with these findings, the present study supports the belief that the primary action of ultrasonic energy in the tissues is liberation of heat which induces a local arteriolar relaxation. The rise of temperature in skeletal muscle is probably of short duration because the resultant hyperemia itself serves to remove heat rapidly. It is very likely that ultrasonic irradiation of moderate intensity did increase muscle temperature and forearm blood flow which subsided before we could make plethysmographic observations. Wise9 has reported that diathermy on the forearm caused an increase in blood flow, but this generally passed within a few minutes. The effects of ultrasonic irradiation appear to be of comparable brevity.

It may be concluded that ultrasonic irradiation of the extremities at tolerable levels of intensity is not an effective means of promoting a sustained increase in blood flow. Such vasodilatation as occurs seems to result from heating of the deep tissues and may be produced more efficiently by immersion of the limbs in warm water or by other simple measures.

Summary

1. The effects of different intensities of ultrasonic irradiation on temperature and blood flow (plethysmographic method) in the forearm have been studied.
2. A consistent, sustained increase in flow occurred as a result of treatment only with high intensities (over 3.0 watts per square centimeter) of ultrasonation.
3. With more tolerable ultrasonic intensities (2.0 watts per square centimeter), vasodilatation was detected only in about one-half of the cases. In the remaining half vasodilatation either did not occur, or was of very brief duration.
4. When ultrasonic irradiation of limbs is sufficient to cause an increased blood flow, the latter is due to vasodilatation in the muscles secondary to a local thermogenic effect.

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REFERENCES

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