Effect of Pulsed Short-wave Diathermy upon Volume Blood Flow Through the Calf of the Leg

PLETHYSMOGRAPHIC STUDIES

LEO J. MORRISSEY, M.A.

The medical use of short-wave diathermy for the generation of heat in the tissues of the body has long been accepted as a therapeutic agent.

Medical diathermies can be classified according to their differences in wave lengths and on the source of the high frequency current. The Federal Communications Commission has assigned the bands from 26.96 to 27.28 megacycles to short-wave diathermy. The center of the frequency of this channel is 27.12 megacycles, and a wave length generally from 10 to 15 meters is produced. Most commercially available short-wave diathermy generators are on this band. With the recent marketing of pulsed short-wave generators, interest has been developed in studying the biological effects of this modality.

Several years ago, Kovacs stated that "it is not possible to predict what would happen if, instead of treating tissues by means of sustained high frequency electrical energy, tissues were subjected to intermittent radio frequency pulses of very high intensity separated by silent periods of sufficient length to allow for the dissipation of heat." 1

The commercial pulsed short-wave diathermy generators provide an output of 27.12 megacycles with a maximum pulse power output of from 1050 to 1333 watts varying with the different manufacturers. The pulse width is 50 microseconds at pulse repetition rates, adjustable in six steps from 80 to 600 pulses per second. The radiating element is enclosed in a cylindrical treatment head, 9 inches in diameter and mounted on an adjustable arm. The wave lengths of pulsed short-wave generators are similar to those produced by continuous short-wave generators.

Pulsed short-wave diathermy is a technique of timing pulses so that the electromagnetic energy is alternately on and off. With relatively low intensities of pulsed power output and frequency of pulses it is possible to irradiate tissue without a resultant increase in temperature. In these cases heat produced from an individual pulse may be dissipated before the subsequent pulse is generated.

REVIEW OF THE LITERATURE

Kemp, Paul, and Hines have shown, using continuous short-wave diathermy in experimental animals, that with temperature increases of 2.7 degrees Centigrade or less there
was no change in blood flow. Seims, Kosman, and Osborne found that it was necessary to increase tissue temperature to 3.6 degrees Centigrade or more in order to demonstrate a significant increase in blood flow. Richardson et al. supported these findings in their studies and stated that "irradiation of peripheral tissues with continuous short-wave diathermy may or may not increase blood flow depending on the degree of tissue hyperemia." Abrahamson studied the effect of continuous short waves on blood flow in human subjects. He also determined changes in tissue temperature and oxygen intake of the tissues. In his investigations the increase in flow as a result of continuous short-wave diathermy was 2.1 ml/min. Skin temperature rose 1.3 degrees Centigrade, subcutaneous temperature 1.5 degrees Centigrade, and muscle temperature 1.9 degrees Centigrade. In seven of the cases the largest rise occurred in the muscle; in two cases, in both muscles and subcutaneous tissue; in two cases, in subcutaneous tissue; in one case, in both subcutaneous tissue and skin; and in two cases, in the skin. His data did not show evidence that a rise in temperature to a definite level is needed in order to obtain an increase in blood flow as has been reported by other investigators. Abrahamson stated that the actual temperature reached is a balance between the heat produced and the ease with which the heat is removed by the increased flow. The fact that increased blood flow accompanies a definite rise in oxygen uptake suggested to him that short-wave diathermy should be limited to portions of the body possessing an adequate arterial circulation which reacts normally to increased oxygen needs of the tissue. Erdman investigated the effect of pulsed short-wave diathermy on blood flow through the digit by means of a volumetric plethysmograph positioned over the second toe. Continuous temperature readings were made from the skin over the dorsum of the foot, the rectum, and the abdominal skin. The subjects were irradiated over the epigastrium with a low average output (16 watts) of pulsed (400 cps) short waves. He found that the abdominal skin temperature increased 0.5 degree Centigrade, skin temperature of the foot 2.0 degrees Centigrade, and approximately 0.1 degree Centigrade rectally. The amplitude of arterial pulse tracings in the toe were increased. Increasing the average power output resulted in greater increases in flow with an average increase in peripheral pulses of 1.75 times the resting pulse. The author interpreted the increase in pulses as an increase in blood flow. Since the tissue in the toe is primarily skin, the technique employed in the above study would primarily evaluate skin circulation rather than circulation through skeletal muscle. Wildervanek, Wakim, Herrick, and Krusen conducted investigations in which they exposed ground horsemeat, in a loaflike form, 20 by 20 by 3.5 cm, and a living animal (dog) to pulsed short-wave energy. The meat was covered with a polyvinyl resin (vinylite) to prevent evaporation and cooling. Three thermistors were placed at a depth of 1.5 cm in different positions in the meat: one in the center, a second at 5 cm distance from the center, and the third at 9 cm distance from the center. The center of the drum electrode of the pulsed short-wave generator was placed over the center of the meat at a distance of 1 cm. Irradiation with 40 watts and 600 cps resulted in a linear progressive rise in temperature at the most peripheral site (4.1° C.) after ten minutes, and (9.1° C.) after twenty minutes. The center site showed a smaller increase (2.0° C.) with the middle site intermediate between these values.

In another series of experiments these au-
EFFECT OF PULSED SHORT-WAVE DIATHERMY ON VOLUME BLOOD FLOW IN LEG

Theors found that by covering the meat with a layer of lard to a depth of 0.5 cm and repeating the same procedures, temperature rises of lower magnitude were observed. The maximum rise was considerably lessened after ten minutes (3.0° C.) and showed an increase after twenty minutes (6.0° C.).

Using a continuous short-wave generator with a power output of 100 ma, they found a similar linear progressive rise in temperature. The magnitude of temperature changes could be varied with both types of short-wave generators by altering the energy output.

They also found a significant increase in tissue temperature in the superficial, subcutaneous, and deep muscle tissues during irradiation of the dog's thigh. The maximum increase in temperature (2.6° C.) occurred in the subcutaneous tissue during a twenty-minute irradiation period.

Several reports have been published resulting from clinical observations of pulsed short-wave energy. The effects of continuous short-wave diathermy on blood flow has been found by many to be related to the amount of hyperthermia produced.

The present study was conducted to determine the effect of pulsed short-wave diathermy on blood flow through the calf of the leg.

METHOD

Venous occlusion plethysmography was used to measure volume blood flow through the calf of the leg. The technique consists of measuring the increase in volume of a limb segment because of an engorgement of the inflowing arterial blood following temporary occlusion of the venous outflow by means of a pneumatic cuff. The rate of swelling can be measured by sealing the limb segment in a rigid container known as a plethysmograph. Imig, Sutfin, and Hines have investigated this method of plethysmography measurements and have determined that it is a satisfactory means of measuring volume blood flow in the extremities.

The technique of venous occlusion plethysmography employed in the present studies has been previously described by Bauer. In this technique, the plethysmograph was filled with water at 33 degrees to 34 degrees Centigrade (approximately skin temperature). Increases in tissue volume following venous occlusion displaced water into a vertical standpipe attached to the top of the plethysmograph. Fluctuations in the height of the column of water in the standpipe were detected by means of a pressure transducer. The output of the transducer was amplified and recorded on an ink-writing oscillograph. Calibration of the apparatus by injecting known volumes of water into the plethysmograph and recording the deflection produced allowed calculation of the rate of inflow of arterial blood in milliliters per minute. The volume of the limb segment within the plethysmograph was determined by water displacement and the volume rate of blood flow expressed as milliliters of flow per 100 milliliters of tissue, encased by the plethysmograph, per minute (ml/100 ml tissue/min).

A pulsed short-wave diathermy generator employed to supply electromagnetic radiation in this study. According to the manufacturer's service manual, the generator provides an output of 27.12 megacycles, a wave length of 11 meters, with a maximum pulse power of 1333 watts. The pulse width is 50 microseconds at pulse repetition rates ranging from 80 to 600 per second. The maximum average power output from the treatment head of the apparatus at 600 pulses per second is 40 watts. It has been stated that at this maximum power output, maximum penetration is achieved without raising the body temperature or producing any appreciable local tissue heating.

In the present study, a 7-inch water-filled (30° to 34° C.) plastic plethysmograph was positioned over the calf of the leg with the proximal end at the tuberosity of the tibia. Twenty-eight normal human subjects—nineteen male and nine female—between the ages of twenty and thirty-nine participated in the investigations. Each subject rested in the supine position on a modified examining table with the leg in place in the plethysmograph. The knee was supported by a felt sling and the foot positioned in a foot support. Venous occlusion was accomplished by inflating an 8-cm pneumatic cuff, which was placed around the lower thigh just above the knee. Rapid inflation of the cuff to the desired pressure was achieved by using an automatic inflation device.
After positioning of the subject in the apparatus, a distal occlusion cuff was placed around the ankle and inflated to approximately 250 mm Hg for the purpose of arresting the circulation through the foot. Under certain conditions blood flow through tissues distal to the plethysmograph may influence the measurements of blood flow through the tissue inside the plethysmograph.\(^\text{15}\) Several values of control blood flow were obtained. The leg was then removed from the apparatus and irradiated with pulsed short-wave diathermy.

The effect of three irradiation procedures on blood flow were studied: (1) irradiation of the calf of the leg for fifteen minutes; (2) irradiation of the epigastrium for fifteen minutes; and (3) irradiation of the calf of the leg for fifteen minutes followed by irradiation of the epigastrium for fifteen minutes. In each procedure blood flow measurements were recorded through the calf of the leg at two-minute intervals.

Additional experiments were carried out on four subjects using pulsed short-wave diathermy at 80 watts average power and a pulse rate of 2000 cps.\(^\text{14}\) According to the manufacturer's information, the irradiation from this power output will create thermal effects similar to continuous short-wave diathermy instruments.\(^\text{14}\) Skin temperature was recorded on the calf of the leg in ten subjects during irradiation of the calf with pulsed short-wave diathermy at an average power output of 40 watts and 600 cps, and in four subjects at an average power output of 80 watts and a pulse rate of 2000 cps. These recordings were made with a calibrated potentiometer using iron-copper skin thermocouples.

In the statistical analysis, paired comparisons of the data were made using Student's t test. Null hypothesis was rejected at the 5 per cent level of significance.

**RESULTS**

Irradiation of the calf of the leg for fifteen minutes with 40 watts of pulsed (600 cps) short-wave diathermy did not result in a statistically significant change in volume blood flow (Table 1). A mean increase did, however, occur. Since it was necessary to remove the plethysmograph during the irradiation of the leg, blood flow in this study was measured only before and after the irradiation.

Values of blood flow measured before, during, and after irradiation of the epigastrium with 40 watts of pulsed (600 cps) short-wave energy are summarized in Tables 2 and 3. There was a mean increase in blood flow during the exposure period, but it was not statistically significant.

Values of blood flow measured before, during, and after irradiation of the epigastrium with 40 watts of pulsed (600 cps) short-wave diathermy preceded by irradiation of the leg are summarized in Table 4 (during exposure) and Table 5 (after exposure). There was no significant change in flow at any time of measurement. A mean increase did, however, occur.

Exposure of the calf of the leg to 80 watts of pulsed (2000 cps) short-wave energy resulted in a statistically significant increase in blood flow (see Table 6).

Irradiation of the leg with 40 watts at 600 cps for fifteen minutes did not significantly raise the skin temperature over the gastrocnemius muscle (see Table 7).

Increasing the intensity to 80 watts with 2000 cps resulted in a significant increase in the skin temperature (see Table 8).

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**TABLE 1**

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</table>


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EFFECT OF PULSED SHORT-WAVE DIATHERMY ON VOLUME BLOOD FLOW IN LEG

TABLE 2

SUMMARY OF VOLUME BLOOD FLOW (ML/100 ML TISSUE/MIN) THROUGH THE CALF OF THE LEG IN NORMAL HUMAN SUBJECTS BEFORE AND DURING EXPOSURE OF THE EPIGASTRIUM TO 40 WATTS OF PULSED (600 CPS) SHORT-WAVE DIATHERMY

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DISCUSSION

Relatively little work has been done on the biological effects of pulsed short-wave diathermy. It has been suggested that the thermal aspect associated with continuous short-wave diathermy may be essentially eliminated by pulsing this energy. Wildervanek et al. found that tissue temperature was not increased when irradiated with comparable amounts of low average outputs of either continuous or pulsed short-wave diathermy.7 With comparable relatively large average outputs, similar tissue temperature increases were found with both forms of this energy.

Richardson et al., Abrahamson, and Wakim reported that continuous short-wave diathermy applied to an extremity will increase blood flow through the deeper tissues of the extremities. However, they all found that the tissue temperature had to be sufficiently increased before an increase in the flow was observed.4, 5, 16 Erdman reported an increase in

TABLE 3

SUMMARY OF VOLUME BLOOD FLOW (ML/100 ML TISSUE/MIN) THROUGH THE CALF OF THE LEG IN NORMAL HUMAN SUBJECTS BEFORE AND AFTER EXPOSURE OF THE EPIGASTRIUM TO 40 WATTS OF PULSED (600 CPS) SHORT-WAVE DIATHERMY

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TABLE 6

SUMMARY OF VOLUME BLOOD FLOW (ML/100 ML TISSUE/MIN) THROUGH THE CALF OF THE LEG IN NORMAL HUMAN SUBJECTS BEFORE AND AFTER EXPOSURE OF THE CALF TO 80 WATTS OF PULSED (2000 CPS) SHORT-WAVE DIATHERMY

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### TABLE 4
SUMMARY OF VOLUME BLOOD FLOW (ML/100 ML TISSUE/MIN) THROUGH THE CALF OF THE LEG IN NORMAL HUMAN SUBJECTS BEFORE, DURING, AND AFTER EXPOSURE OF THE EPIGASTRIUM TO 40 WATTS OF PULSED (600 CPS) SHORT-WAVE DIATHERMY PRECEDED BY EXPOSURE OF THE CALF

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### TABLE 5
SUMMARY OF VOLUME BLOOD FLOW (ML/100 ML TISSUE/MIN) THROUGH THE CALF OF THE LEG IN NORMAL HUMAN SUBJECTS BEFORE, DURING, AND AFTER EXPOSURE OF THE EPIGASTRIUM TO 40 WATTS OF PULSED (600 CPS) SHORT-WAVE DIATHERMY PRECEDED BY EXPOSURE OF THE CALF

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### TABLE 7
SUMMARY OF SURFACE TEMPERATURE (DEGREES FAHRENHEIT) OF THE CALF OF THE LEG IN HUMAN SUBJECTS DURING EXPOSURE OF THE CALF TO 40 WATTS OF PULSED (600 CPS) SHORT-WAVE DIATHERMY.

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<td>.442</td>
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<td>1.14</td>
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</tr>
<tr>
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<td>80</td>
<td>70</td>
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<td>30</td>
<td>30</td>
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</tr>
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### TABLE 8
SUMMARY OF TEMPERATURE (DEGREES FAHRENHEIT) OF THE CALF OF THE LEG IN NORMAL HUMAN SUBJECTS DURING EXPOSURE OF THE CALF TO 80 WATTS OF PULSED (2000 CPS) SHORT-WAVE DIATHERMY.

<table>
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<th>Minutes during Exposure</th>
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<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>9</th>
<th>11</th>
<th>13</th>
<th>15</th>
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<tr>
<td>Mean</td>
<td></td>
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<td>90.89</td>
<td>91.92</td>
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<td>95.67</td>
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<td>2.00</td>
<td>2.95</td>
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EFFECT OF PULSED SHORT-WAVE DIATHERMY ON VOLUME BLOOD FLOW IN LEG
circulation through the skin of the toe during irradiation of the epigastrium with a low aver­
age output of pulsed short waves without a significant increase in body temperature, which suggested reflex vasodilation.6

Two methods of irradiation with pulsed short-wave energy have been used clinically. These are: (1) direct irradiation of the tissue in question, and (2) irradiation of an area, such as the epigastrium, remote from the tissue in question. Using a relatively low average output (40 watts) of pulsed short waves, it was found in the present study that neither of the two above procedures caused a significant increase in skin temperature or blood flow through the calf of the leg. In addition, it was found that irradiation of the leg followed by irradiation of the epigastrium did not significa­ntly increase tissue temperature or peripheral blood flow. It can be pointed out, however, that the mean in the above studies of both tissue temperature and blood flow was increased but was not statistically significant. Perhaps more subjects or longer periods of exposure might have resulted in statistically significant in­creases.

Irradiation of the calf of the leg with 80 watts of pulsed short-wave energy at 2000 cps resulted in a significant increase in both skin temperature and volume blood flow. These results suggest that pulsed short-wave energy may increase muscle blood flow only when the temperature of the tissue in question is increased. This is qualitatively similar to the findings reported by others using continuous short-wave energy.

No evidence for reflex vasodilation of skeletal muscle blood vessels was found in the present study. To permit evaluation of a possible quantitative relationship between blood flow and tissue temperature increase that resulted from pulsed short waves, more data would be required; perhaps different intensities and durations of exposure should be used.

SUMMARY

The effect of pulsed short-wave diathermy on volume blood flow and skin temperature in the calf of the leg was studied. Irradiation of the leg alone or irradiation of the leg followed by irradiation of the epigastrium, with 40 watts average power at 600 cps, did not significantly increase either tissue temperature or blood flow.

Irradiation of the calf of the leg with 80 watts average power output at 2000 cps signifi­cantly increased both tissue temperature and blood flow.

These findings suggest that pulsed short­wave energy may result in an increased blood flow through skeletal muscle only when the temperature of the tissue is increased. Similar findings have been reported by others using continuous short-wave energy.

REFERENCES