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Changes in Peripheral Blood Flow Produced by Short-Wave Diathermy

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Although short-wave diathermy applied to human subjects and dogs has been shown by various investigators to effect a rise in tissue temperature, a concomitant increase in blood flow has not been universally established. Wisc, using the venous occlusion plethysmographic method, noted a definite rise in blood flow in the forearm of ten human subjects. Wakim and his associates performed the same type of study on the upper and lower extremities and reported an increase in circulation in the majority of the subjects, while a small percentage demonstrated an actual decrease. The same workers, using a flow meter, generally found an augmentation in blood flow in the hind limbs of dogs, with a reduction in some instances. Siems and co-workers, also working with dogs, observed a consistent increase in local circulation.

On the other hand, Kemp and his associates reported that diathermy produced a decrease in blood flow in the femoral artery of anesthetized dogs, despite a rise in deep tissue temperature of two to three degrees. Flax and his associates obtained variable results in the digits of human subjects, and Millard using the rate of clearance of radioactive sodium in the muscles of the lower extremity, also observed inconsistent changes.

On the basis of their studies on dogs exposed to diathermy, Richardson and his group concluded that the therapeutic dosages most frequently employed for humans probably would be insufficient to induce appreciable changes in blood flow in deep tissues.

Because of the conflicting results obtained by different investigators, it was decided to study the effect of short-wave diathermy on blood flow through the forearm of normal human subjects, using the venous occlusion plethysmographic method. The purpose of the investigation was twofold: (1) to determine whether or not diathermy applied in a manner similar to that used clinically would produce an increase in circulation in a normal forearm, and (2) if this did occur, to locate the vascular bed or beds mainly responsible for the change.

Clinical Material and Method

Twenty-six experiments were performed on 13 normal healthy subjects ranging in age from 23 to 50 years. Five were women and eight were men. The segment type of venous occlusion plethysmograph, containing a heater and propeller blades, was used to obtain blood flow records from the forearm (fig. 1). The apparatus was properly insulated to protect the skin of the forearm and wrist from heat concentrated in the metal as a result of the application of the diathermy. An air transmission recording system was used, consisting of a Brodie's bellows and an ink-writing lever which recorded on a long-paper kymograph. All studies were performed in a temperature-regulated room with the temperature at 24 C. and the humidity at 56 per cent. During the entire period of observation, attempts were made to minimize psychic stimuli as much as possible.

The diathermy apparatus used operated at a frequency of 27.12 megacycles per second, corresponding to a wave length of 11.06 meters. A capacitance...
field was formed by two air-spaced plate electrodes, one placed over the shoulder and the other over the dorsum of the hand, while the forearm was enclosed in the water-filled plethysmograph (fig. 1).

In an attempt to maintain the dosage of diathermy as constant as possible in the different experiments, the output of the machine was always kept at an arbitrary setting of 25, as indicated on the output meter on the instrument board, while the relationship of the plates to the skin of the dorsum of the hand and shoulder was altered until the subject felt a comfortable sensation of heat equally in both sites. It is recognized that the use of such a purely subjective response to control energy input may lead to the employment of variable dosages of diathermy, even for the same individual on different occasions. However, at present no reliable method for the objective determination of energy input is available. In each experiment diathermy was applied for 34 minutes.

After the subject was left in the temperature-regulated room for approximately 40 minutes, to permit equilibrium to be reached between the temperature of the trunk and limbs and that of the environment, the forearm was placed in the plethysmograph and the apparatus was made watertight according to the technic previously described. Two blood flow experiments were performed on each subject. In the first the plethysmograph was filled with water at 32°C. and maintained at this level throughout the experimental period. In the second test performed about one week later, the bath temperature was kept at 45°C. In order to be certain that the full effect of the heat on the cutaneous vessels had been achieved before diathermy was applied, the control period with the bath temperature at 45°C. was frequently prolonged to about one hour. By means of the heater and propeller blades in the

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In all experiments a Liebel-Flarsheim frequency-controlled short-wave diathermy instrument was used (model SW-460).

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![Diagram of apparatus](image-url)
plethysmograph, the bath temperature for each set of experiments was maintained within one degree of the desired level during the entire period of observation.

In each experiment two to three blood flow recordings were taken in rapid succession every 3 to 4 minutes during the control period of approximately 45 minutes, during the application of diathermy, and in the postdiathermy period. The experiment was terminated when it appeared that the blood flow level had fallen to that of the control period. In all, 45 to 55 blood flow readings were obtained on each subject at a specific bath temperature. The average duration of the experimental period was 2 hours.

The results of each experiment were plotted on graph paper with the abscissa representing time and the ordinate, blood flow. The excess blood flow over and beyond the control level was obtained separately for the period of application of diathermy and for the postdiathermy period. This was accomplished by determining the area under each portion of the curve, using a planimeter. The total excess blood flow elicited by short-wave diathermy was obtained by adding the two figures.

It was believed that with this approach much more pertinent information regarding the effectiveness of diathermy as a vasodilating procedure would be available than from the usual method of comparing the percentage increase over the control level of the blood flow reading representing the maximal peak of the vascular response. The latter approach appears to be of little value, since it in no way takes into consideration the magnitude of the change in blood flow occurring both during and after application of diathermy. In fact, comparison of data obtained in such a manner may lead to misleading or fallacious conclusions.

Results

*Batb Temperature of 32 C.:* Thirteen experiments were performed on the forearm at a bath temperature of 32 C., with the control readings averaging 7.2 cc. per minute per 100 cc. of limb volume (range of 4.7 to 9.5 cc.).

With the beginning of the period of diathermy, in each instance there was an almost immediate increase in blood flow (fig. 2A), with the peak of the response occurring in an average of 30 minutes (range of 20 to 34 minutes) after the procedure was started (figs. 3 and 4).

After the period of diathermy was terminated, in eight cases the blood flow continued to rise slightly, reaching a peak in an average of 6 minutes (range of 2 to 11 minutes) (fig. 3). In the remaining five cases, the curve of increased blood flow fell during the postdiathermy period from the peak attained during diathermy (fig. 4). For the entire group the average duration of the increase in circulation in the postdiathermy period averaged 45.7 minutes (range of 31 to 66 minutes). At no time was there a significant fall below the control blood flow level in the postdiathermy period.

In all but two cases, the amount of excess blood flow observed during the application of diathermy at a bath temperature of 32 C. was less than that of the postdiathermy period (table 1). The average of the excess blood flow noted during diathermy was 33.5 cc. (range of 8.6 to 75.8 cc.), as compared with 44.9 cc. (range of 13.9 to 98.7 cc.) for the postdiathermy period. The total excess blood flow elicited by application of diathermy was an average of 78.5 cc. (range of 22.5 to 173.9 cc.).

*Bath Temperature of 45 C.:* Thirteen experiments were performed on the forearm at a bath temperature of 45 C., with the control readings averaging 7.2 cc. per minute per 100 cc. of limb volume (range of 4.7 to 9.5 cc.).

At the beginning of the period of diathermy, in each instance there was an almost immediate rise in blood flow (fig. 2B), with a peak of the response occurring in an average of 27 minutes (range of 16 to 33 minutes) after the procedure was started (figs. 3 and 4).

After the period of diathermy was terminated, in five cases the blood flow continued to rise slightly, reaching a peak in an average of 4 minutes (range of 2 to 12 minutes) (fig. 3). In the remaining eight cases, the curve of increased blood flow fell during the post-
Fig. 2 — Reproductions of actual records of blood flow obtained from forearm. The abrupt ascent of baseline is the result of sudden application of a pressure of 70 mm. Hg around the arm (venous occlusion pressure) sufficient to prevent all blood in forearm from flowing out, at least for the first few seconds, while not interfering with arterial inflow. Steepness of slope is a reflection of rate of blood flow into limb. Calibration scales, on the left side of figure. Time in fifths of second. A, Blood flow readings obtained at both temperature of 32° C: 1. control period, 2. during application of diathermy; 3. after termination of diathermy. B, Blood flow readings obtained at both temperature of 45° C: 4. control period, 5. during application of diathermy; 6. after termination of diathermy. Figures under curves indicate calculated blood flow in cc per minute per 100 cc. limb volume derived from record.

Fig. 3 — Graphs depicting excess blood flow entering forearm of subject J.S. as a result of application of 34 minutes of diathermy. Abscissa represents time in minutes and ordinate, blood flow per minute per 100 cc. limb volume. Area enclosed by open circle and solid line designates excess blood flow obtained at both temperature of 32° C: during diathermy, 75.8 cc.; after diathermy, 57.2 cc.; total excess blood flow, 133 cc. Area enclosed by solid circle and dotted line designates excess blood flow obtained at both temperature of 45° C: during diathermy, 56.1 cc.; after diathermy, 69.9 cc.; total excess blood flow, 126 cc.

diathermy period from the peak attained during diathermy (fig. 4). For the entire group the average duration of the increase in blood flow in the postdiathermy period averaged 36.9 minutes (range of 9 to 16 minutes). In five cases the blood flow curve after reaching the baseline significantly dropped below it. In two other instances a moderate drop occurred and in the remaining six either a slight fall or no fall was observed.

In eight out of thirteen cases the
amount of excess blood flow observed during the application of diathermy was greater than in the postdiathermy period, in one both were the same, and in four, the greater increase was present in the postdiathermy period (table 1). The average excess blood flow during the period of diathermy was 53.5 cc. (range of 29.4 to 104.0 cc.), as compared with 44.8 cc. (range of 8.4 to 104.6 cc.) for the postdiathermy period. The total excess blood flow elicited by the application of diathermy was an average of 98.3 cc. (range of 44.2 to 153.0 cc.).

**Comparison of the Results Obtained at Bath Temperatures of 32 and 45 C.:** Comparison of the graphs representing the blood flow response to diathermy at a bath temperature of 32 C. with those obtained at 45 C. revealed certain similarities and differences. Under both circumstances there was a definite increase in blood flow through the forearm during the period of application of diathermy and for some time afterward (figs. 3 and 4). The location of the peak of the blood flow response during the period of diathermy was also approximately the same for the two bath temperatures, that is, near the end of the period of application. Furthermore, under both conditions, in approximately one-half of the cases there was a continued rise in blood flow in the postdiathermy period. The total excess blood flow elicited by the application of diathermy was an average of 53.5 cc. (range of 29.4 to 104.0 cc.). Among the observed differences in responses was a longer period of increased blood flow after the termination of diathermy with a bath temperature of 32 C. than at 45 C. (45.7 minutes as compared with 36.9 minutes). Another was the finding that in no instance did the readings in the postdiathermy period significantly fall below the level of the control at a bath temperature of 32 C., while this occurred seven times at 45 C.
Finally, at a bath temperature of 32 C., the excess blood flow during the period of application of diathermy was generally less than that of the postdiathermy period (an average of 33.5 cc. as compared with 44.9 cc.), while at a bath temperature of 45 C., the reverse was true (an average of 53.5 cc. for the period of diathermy, as compared with 44.8 cc. for the postdiathermy period).

In the group as a whole, the total excess blood flow elicited by the application of diathermy was much less at a bath temperature of 32 C. (an average of 78.5 cc.) than at 45 C. (an average of 98.3 cc.). When the responses of a specific individual to the two bath temperatures were compared, the following data were obtained: In six subjects the total excess blood flow was definitely greater at a bath temperature of 45 C. than at 32 C. (D.A., G.M., P.B., E.B., L.L., and A.P.), while in four the results were approximately the same (M.S., S.L., J.S., and A.H.); in two subjects (S.B. and A.S.) the response was somewhat greater at 32 C. than at 45 C., while in only one (M.P.) was it definitely greater (see Table 1).

**Table 1: Effect of Short-Wave Diathermy on Blood Flow in the Forearm.**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Control</th>
<th>During</th>
<th>After</th>
<th>Total</th>
<th>Control</th>
<th>During</th>
<th>After</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.A.</td>
<td>2.3</td>
<td>32.2</td>
<td>26.8</td>
<td>58.5</td>
<td>9.5</td>
<td>104.0</td>
<td>49.0</td>
<td>153.0</td>
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<tr>
<td>G.M.</td>
<td>1.7</td>
<td>9.6</td>
<td>13.9</td>
<td>22.5</td>
<td>6.7</td>
<td>33.6</td>
<td>104.6</td>
<td>138.2</td>
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<tr>
<td>P.B.</td>
<td>1.4</td>
<td>23.2</td>
<td>66.8</td>
<td>92.0</td>
<td>8.3</td>
<td>54.4</td>
<td>46.6</td>
<td>101.0</td>
</tr>
<tr>
<td>E.B.</td>
<td>1.9</td>
<td>28.6</td>
<td>40.6</td>
<td>69.2</td>
<td>7.7</td>
<td>47.4</td>
<td>45.3</td>
<td>92.7</td>
</tr>
<tr>
<td>L.L.</td>
<td>1.5</td>
<td>12.5</td>
<td>27.7</td>
<td>40.0</td>
<td>6.3</td>
<td>63.9</td>
<td>22.5</td>
<td>86.4</td>
</tr>
<tr>
<td>A.P.</td>
<td>2.0</td>
<td>16.6</td>
<td>16.9</td>
<td>33.5</td>
<td>4.7</td>
<td>56.1</td>
<td>50.7</td>
<td>106.8</td>
</tr>
<tr>
<td>M.S.</td>
<td>1.8</td>
<td>22.3</td>
<td>59.8</td>
<td>82.1</td>
<td>9.1</td>
<td>46.7</td>
<td>30.7</td>
<td>77.4</td>
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<tr>
<td>J.L.</td>
<td>2.7</td>
<td>36.2</td>
<td>34.0</td>
<td>64.2</td>
<td>7.1</td>
<td>60.7</td>
<td>8.4</td>
<td>69.1</td>
</tr>
<tr>
<td>J.S.</td>
<td>1.8</td>
<td>75.3</td>
<td>57.2</td>
<td>133.0</td>
<td>5.5</td>
<td>56.1</td>
<td>69.9</td>
<td>126.0</td>
</tr>
<tr>
<td>A.H.</td>
<td>0.9</td>
<td>43.2</td>
<td>48.0</td>
<td>91.2</td>
<td>5.1</td>
<td>52.9</td>
<td>40.3</td>
<td>93.2</td>
</tr>
<tr>
<td>S.B.</td>
<td>2.4</td>
<td>23.9</td>
<td>32.4</td>
<td>56.3</td>
<td>7.1</td>
<td>29.4</td>
<td>14.8</td>
<td>44.2</td>
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<tr>
<td>A.S.</td>
<td>1.5</td>
<td>40.6</td>
<td>71.7</td>
<td>112.3</td>
<td>6.7</td>
<td>42.1</td>
<td>55.6</td>
<td>97.7</td>
</tr>
<tr>
<td>M.P.</td>
<td>1.4</td>
<td>74.3</td>
<td>98.7</td>
<td>173.0</td>
<td>8.4</td>
<td>54.0</td>
<td>44.5</td>
<td>98.5</td>
</tr>
</tbody>
</table>

**Discussion**

The results of the present study support the view that when diathermy is applied to an extremity in dosages comparable to those used clinically, invariably a definite increase in blood flow will be produced. Evidence has also been accumulated to indicate that at a bath temperature of 45 C. the vascular bed primarily affected by the diathermy is in the muscular tissues of the limb. The basis for arriving at such a conclusion will be presented subsequently.

It is generally accepted that at a bath temperature of 32 C. the vessels in the limb, both superficial and deep, are in a physiologic state, that is, neither excessively constricted nor excessively dilated. Such a situation is similar to that produced by an environmental air temperature of 25 C. Under such circumstances, therefore, any increase in blood flow elicited by diathermy could be attributed to vascular changes either in skin and subcutaneous tissue, in muscle, or in both.

On the other hand, at a bath temperature of 45 C. the heat of the water acts as a very potent agent for the production of almost maximal vasodilation of the surface vessels and possibly of those in the superficial muscle layers. As a result, it can be assumed that the arterial system, in the cutaneous and subcutaneous tissues at least, is in such a state of relaxation that other vasodilating procedures should have little or no additive effect. On this basis, the fact that in all subjects a significant increase in blood flow in the forearm was elicited by diathermy at a bath temperature of 45 C. has great importance. For,
with the cutaneous and subcutaneous vessels fully dilated, such a change can be attributed only to an augmentation in circulation in the muscle tissues.

It is conceivable that a higher bath temperature would have a greater effect but it has been found that 45°C is the maximal temperature which can be tolerated comfortably by most individuals. Beyond that level, pain is produced, which acts as a strong vasoconstricting stimulus to counteract in part the direct vasodilating effect of the heat.

The fact that in all of the subjects but one the excess blood flow resulting from diathermy at a bath temperature of 45°C was either greater than, the same as, or slightly less than that at 32°C is also of interest. It suggests that the vascular changes in circulation at a bath temperature of 32°C could be caused by the same mechanisms operating at a higher temperature, namely, vasodilatation of muscle blood vessels. It is realized of course, that such a view is based on indirect evidence. Opposed to it is the possibility that a critical muscle temperature may be required to elicit an increased muscle circulation and that such a level is not reached at 32°C but is at 45°C.

To explain the finding that in six subjects diathermy produced a much greater increase in blood flow at a bath temperature of 45°C than at 32°C, it is necessary to review briefly the mechanisms which come into play in the dissipation of heat from the body. As soon as heat accumulates in the muscles, after the use of an agent such as diathermy, a gradient is created between the artificially produced high tissue temperature and that of the environment. The steeper the gradient, the more rapid is the loss of heat by conduction and convection from the interior of the limb to the skin and by radiation from this structure to the environment.

Another mechanism is purely a vascular one, involving vasodilatation of the vessels in the muscles initiated by the heat. The resulting increase in circulation acts as an effective means of removal of heat, provided the temperature of the tissues surrounding the vessels is higher than that of blood. Furthermore, the greater the tissue temperature, the more marked is its vasodilating effect. With the source of heat deposition constant, the magnitude of the increase in muscle blood flow elicited by diathermy therefore will vary inversely with the efficiency of the mechanism operating to cause loss of heat to the environment by convection, conduction, and radiation.

At a bath temperature of 32°C an adequate gradient exists between the high muscle temperature produced by diathermy and the temperature of the water surrounding the limb, thus contributing to considerable loss of heat from the muscles through convection and conduction.

On the other hand, at a bath temperature of 45°C the existing gradient between tissue and environmental temperatures is obviously much less, and hence the heat deposited in the muscle by diathermy tends to pile up to a greater degree than at 32°C. The higher muscle temperature acts as an increased stimulus to cause further dilatation of muscle vessels, this manifesting itself in the form of a more marked muscle blood flow.

The greater response to diathermy frequently observed at a bath temperature of 45°C may have some clinical application. For example, if a jacket of heat could be produced around a limb simultaneously with the use of diathermy to the area, the vasodilating effect of the latter agent might be enhanced or a smaller dosage might be adequate. It is possible that such a situation could be produced by the combined use of diathermy and infrared or diathermy and fomentations covering the limb.

Summary and Conclusion

The results of the present study on human subjects support the view that diathermy has a consistently potent vasodilating effect and that at a bath temperature of 45°C the action is primarily upon the muscle vessels. Whether the same situation exists at a bath temperature of 32°C cannot be stated conclusively, although there is some suggestive evidence in support of this view. The finding in about one-half of the cases of
a greater vascular response to diathermy at a bath temperature of 45 C. than at 32 C. may have clinical implication and application.

References

SLIDEFILM PINPOINTS QUACK DEVICES

More than a dozen mechanical quack devices and gadgets play the villain in a color slidefilm with sound just released by the AMA Bureau of Investigation. The 15-minute filmstrip, "Mechanical Quackery," is supplemented by narrative description of the devices and the fraudulent uses to which they have been put. It is available on loan to medical societies, service and fraternal groups and schools.

The film is described as a public education experiment. The slidefilm is a flexible and effective medium to use in exposing some of the quacks to the public. It may be used by medical societies or individual doctors as a tool in a concerted program to fight quackery. It is valuable, 'too, when used by lay or professional groups to alert their members or the community to the harm caused by quacks who use these worthless machines and devices as cure-alls.

Twenty-five sets of the film and record are in the AMA Bureau of Investigation lending library. Requests should be addressed to the Bureau.
(Note: Equipment needed to show "Mechanical Quackery": A sound slidefilm projector—or a filmstrip projector with a 33 1/3 RPM turntable. Strip has 60 frames. Record is 12-inch.)