A COMPARATIVE STUDY OF SHORT WAVE AND MICROWAVE DIATHERMY ON BLOOD FLOW *

The Role of the Somatic and Sympathetic Nerves in the Vascular Response to Deep Tissue Heating

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Introduction

It has been universally accepted that local heating of an extremity increases the blood flow to it. Recently, however, Kemp, Paul and Hines[1] have reported that, although blood flow in the femoral artery of the dog is increased by microwave diathermy, heating with short wave diathermy left blood flow unchanged or actually decreased. If this work could be confirmed, it would necessitate a complete revision of the present concepts of the physiologic effects of heating. To this end, the effects of microwave and short wave diathermy upon blood flow in the femoral artery were studied in a series of normal dogs and dogs with unilateral denervation of the hind extremity.

Methods

The studies were carried out upon pentobarbital-anesthetized dogs in a room kept at 30 ± 1 C. The high room temperature was necessary to prevent loss of body heat and a rapid fall in flow in the femoral artery.

The animals were placed on their backs in a troughlike dog board with the hind extremities partially extended and supported on approximately the same level as the trunk. The femoral arteries were exposed bilaterally from the inguinal ligament distally about 10 cm. The arteries were cannulated proximally and distally as close to the inguinal ligament as possible and without severing the arteries in order to prevent retraction. The cannulas were attached on each side to "bubble flow meters" which were slight modifications of the design of Leden and coworkers.[2] Readings were taken bilaterally and simultaneously. To prevent clotting 100 mg. of dicumarol was given orally twenty-four hours before operation and 100 mg. of heparin intravenously at the time of operation.

In addition, an iron-constantan thermocouple inserted into a 16 gauge hollow needle was placed into the gastrocnemius muscle to measure temperature before and after heating. These readings were taken only to be certain that a fair degree of heating had been produced; for, of course, temperature change depends not only on the energy absorbed but also on the rate of heat dissipation by the changing blood flow.

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* Read at the Twenty-Sixth Annual Session of the American Congress of Physical Medicine, Washington, D. C., Sept. 8, 1948.
1. Kemp, C. P.; Paul, W. P., and Hines, H. M.: Arch. Phys. Med. 29:12, 1948.
2. Leden, V. M.; Herrick, J. F.; Wakim, K. G., and Krusen, F. H.: Brit. J. Phys. Med. 10:177, 1947.

Microwaves (frequently of 2,450 megacycles) were applied by means of a "four inch director" placed 2 inches from the skin. Short wave (induction method) diathermy (frequency of 27.33 megacycles) was applied by means of a standard hinge-jawed drum adjusted to surround the leg. In both cases, after a one hour control period, heating was directed to the region of the gastrocnemius for twenty minutes.

The dogs with unilateral denervation of the hind extremity had one of three following lesions: section of ventral nerve roots from the fourth to the seventh lumbar segment; section of dorsal and ventral roots from the fourth to the seventh lumbar segment, or section of femoral, sciatic and obturator nerves peripherally. These animals were studied twelve weeks after production of the lesions. It is well to point out the exact type of lesions with which we were dealing. There is good agreement[3] that in a variety of animals the major sympathetic outflow to the hind extremities occurs between thirteenth thoracic and the third lumbar segment, and with an occasional contribution from the fourth lumbar roots. From the observations of Huddleston and White[4] and Frederick of this laboratory,[5] the major motor outflow to the muscles of the dog's leg occurs from the fourth to seventh lumbar roots. For these reasons, it is possible to produce a complete motor paralysis of these muscles with a minimum of interference with sympathetic supply. These lesions also resulted in a considerable paralysis of the thigh muscles. Since all available evidence[6] indicates that the sympathetic fibers to an extremity are contained in its somatic nerves, peripheral nerve section should produce a total denervation. Thus, the experimental animals represented three distinct types of lesion: (a) pure motor loss; (b) combined motor and sensory loss, and (c) motor, sensory, and autonomic loss.

To compensate for distortion resulting from spontaneous fluctuations in blood flow, flow changes were analyzed on the basis of the difference between control and heated sides just before and at the end of heating. This is designated "adjusted flow increase." Statistical significance was determined by the method of paired comparison.

Results

An examination of table 1 and chart 1 reveals that there is a significant increase in blood flow upon the application of either form of heating in normal animals and animals with root lesion. Because of the limited number of animals with root lesions, the results are grouped for analysis and presentation according to the type of heating. In all cases the response is essentially the same.

In dealing with the peripheral nerve lesion group it became obvious that the response typical of the other animals could not be obtained. Since there were not enough dogs in the peripheral nerve lesion group to permit separate analysis of microwave and short wave heating and since it was quite clear that the two methods of heating were equally effective in the other groups, for purposes of comparison the animals were arranged according to the type of lesion represented. These data assembled in table 2 and chart 2 demonstrate that while the response in the animals with root lesions is essentially

3. Langley, V. N.: Physiol. 12:347, 1891. Sheehan, P., and Marrazzi, A., S.: J. Neurophysiol. 4:68, 1941.

4. Huddleston, O. L., and White, C. S.: Am. J. Physiol. 138:772, 1943.

5. Frederick, J. N.: Unpublished observations.

6. Woollard, H. H.: Heart 13:319, 1926. Blair, P. M., and Bingham: J. Anat. 63:162, 1928. Morton, J. J., and Scott, W. V.: J. Clin. Investigation 9:233, 1930. Woollard, H. H., and Phillips: J. Anat. 67:18, 1932.

TABLE 1. — *The Effect of Short Wave and Microwave Diathermy upon Blood Flow.*

Type of Animal	Type of Heating	No. of Animals	Mean Blood Flow, cc. Min. Before Heating: Control Leg	Before Heating: Leg Selected for Heating	After Heating: Control Leg	After Heating: Leg Selected for Heating	Mean Adjusted Flow Increase and Standard Deviation	T Ratio	Temperature of Gastrocnemius °C.: Before Heating	After Heating	Mean Increase in Temperature, °C. and Standard Deviation	T Ratio
Normal	Short wave	10	51.5	52.9	42.7	60.6	16.5	6.8	2.43*	37.9	41.5	3.6	.76	8.61†
Normal	Micro-wave	10	44.8	47.0	42.2	59.0	14.6	5.3	2.75*	38.4	43.6	5.2	.87	11.1
Ventral and dorsal-ventral root section	Short wave	7	33.4	31.5	28.1	36.7	10.5	3.55	2.96*	37.8	41.6	3.8	1.7	4.1†
Ventral and dorsal-ventral root section	Micro-wave	9	29.6	29.2	21.0	39.9	19.5	3.43	5.69†	37.7	43.9	6.2	1.1	10.5†

* Significant on 5 per cent level.
† Significant on 1 per cent level.

the same as in the normal dogs, significant increases in flow could not be obtained in those animals subjected to peripheral nerve section.

Comment

These experiments clearly demonstrate that short wave and microwave diathermy are equally effective in producing increased blood flow in the hind extremities of normal dogs.

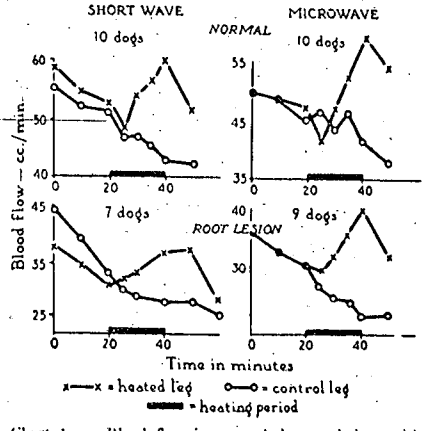

Chart 1. — Blood flow in normal dogs and dogs with root lesions upon application of short wave and microwave heating.

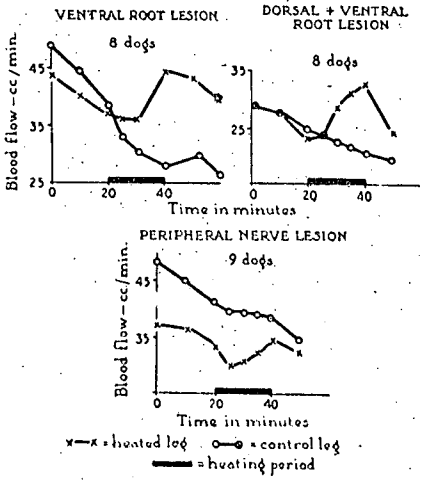

Chart 2. — Blood flow in dogs with ventral root lesion, ventral and dorsal root lesion and peripheral root lesion.

TABLE 2. — *The Effect of Various Nerve Lesions upon the Vascular Response to Heating.*

Type of Animal	Type of Heating	No. of Animals	Mean Blood Flow, cc. Min. Before Heating: Control Leg	Before Heating: Leg Selected for Heating	After Heating: Control Leg	After Heating: Leg Selected for Heating	Mean Adjusted Flow Increase and Standard Deviation		T Ratio	Temperature of Gastrocnemius °C. Before Heating	After Heating	Mean Increase in Temperature, °C, and Standard Deviation		T Ratio
Ventral root section	Short and Microwave	8	38.0	36.8	27.6	44.9	17.9	4.9	3.65*	37.1	42.2	5.1	2.5	5.43*
Dorsal and ventral root section	Short and microwave	8	24.6	23.6	20.6	32.2	13.8	3.1	4.52*	38.4	43.7	5.3	1.4	10.19*
Peripheral nerve section	Short and microwave	9	41.8	33.1	38.5	34.7	5.0	4.7	1.06	37.9	42.8	4.9	1.1	7.76*

*Significant on 1 per cent level.

On examining the data of Kemp, Paul and Hines,[1] one notes that, when microwave diathermy was successfully applied, the initial flow rates averaged 62.5 cc. per minute and increased with heating to an average of 101.7 cc. per minute. However, in their unsuccessful attempts to increase blood flow with short wave diathermy, the initial flow readings averaged 104.3 cc. per minute, or about the same as the average increase after microwave heating. Thus it may be possible that the extremities of the dogs used in the short wave diathermy experiments were initially in a state of vasodilation, which may have masked any vascular response to heating.

Although the root lesion animals, whose sympathetic nerves were intact, responded to heating in essentially the same manner as the normal dogs, the peripheral nerve lesion animals, whose sympathetic outflows had been interrupted, failed to show this response. It is well known that the sympathetic nerves are necessary for local vascular reactions of the extremities.[7] Up to this time there has been no evidence regarding their possible role in the reactions to local heating. Our results strongly suggest that in the dog the sympathetic nerves may be essential for the typical reactions to local deep tissue heating.

Wilkins and Eichna[8] reported that in man a sympathectomized forearm did not undergo as great a flow increase as the normal forearm when heated with water. They may have been observing the same phenomenon. The rationale of heat applications in the treatment of cases of peripheral nerve lesion is open to question and should be reinvestigated.

Conclusions

1. Short wave and microwave diathermy are equally effective in increasing local blood flow in the hind extremity of the normal dog.

2. Loss of motor or sensory innervation to the part does not affect the essential nature of the vascular response to heating.

7. Abramson, P. L.: Vascular Responses in the Extremities of Man in Health and Disease, Chicago, University of Chicago Press, 1944, p. 98.
8. Wilkins, R. N., and Eichna, L. W.: Bull. Johns Hopkins Hosp. 68:425, 1941.

3. Evidence is presented suggesting that the integrity of the sympathetic outflow in the dog is necessary for the typical vascular response to local heating.

4. There is no evidence that any known method of heating possesses properties which have any specific effect on blood flow.

Discussion of Papers by Siems, et al., and Worden, et al.

Dr. Harry M. Hines (Iowa City): Osborne and Holmquest have pointed out that the effectiveness of diathermy for producing tissue temperature elevation will depend upon (1) the efficiency of the circulating blood in dissipating the heat generated; (2) the thermal conductivity of the contiguous tissues; (3) the thermal capacity of the tissues absorbing the energy, and (4) the rate at which energy is being absorbed. It seems to me that a fifth factor must be considered—namely, the effect of the local hyperthermia upon the metabolism and consequent heat production in the treated tissue itself. The augmented heat production would result from the hyperthermia produced by diathermy but would involve a different mechanism. For example, a rise of body temperature of 9.4 degrees (F.) has been found to increase the heat production of the body by 65 per cent. Probably a much higher per cent increase would be found for such tissue as muscle. Comparable increases in the limb tissue temperature of dogs can be produced by short wave diathermy and by microwaves. The tissue temperature increases when measured at cutaneous, subcutaneous, 1.5 cm. and 3 cm. levels show a temperature rise gradient which decays from without inward. The temperature decline following irradiation is similar in these two frequences of electromagnetic waves.

My colleagues and I have been able to confirm the findings as to the effects of ischemia upon tissue temperature increases. In addition, I wish to point out that the fluids in avascular or relatively avascular areas present vulnerable target areas for overheating effects during irradiation treatments with microwaves. We have found that a single treatment for ten minutes at a director distance of 5 cm. with a power output of 100 watts raises the corneal temperature of rabbits to 46 C. (vitrous humor temperature = +49 C.). In many animals after a single treatment of this type lenticular opacities or cataracts develop within six to twenty-four days. This observation would have been missed in acute experiments.

I wish to make a few comments concerning the effect of diathermy upon blood flow. It is well recognized that heat usually causes vasodilation in cutaneous and other superficial tissues, but there is a paucity of information concerning the effect of heat upon the blood flow through deeper tissues, such as skeletal muscle.

Siems, Kosman and Osborne have confirmed our findings as to the effects of heating with microwaves upon blood flow in the hindlimbs of anesthetized dogs. In both laboratories diathermy treatments failed to increase the blood flow through denervated limbs. I agree with the conclusion, "The rationale of heat applications in the treatment of cases of peripheral nerve lesion is open to question and should be reinvestigated."

Siems, Kosman and Osborne found an increase at the 5 per cent level in the blood flow of the hindlimbs of anesthetized dogs treated with short wave diathermy. In our laboratory the average values for blood flow during short wave diathermy showed a decrease. In our series of dogs treated with short wave diathermy the final temperature of the gastrocnemius averaged 103.6 F.; in Siems, Kosman and Osborne's experiments the final temperature averaged 106.7 F. — i. e., over 3 degrees higher. Our final muscle temperatures with microwave treatment averaged 108.3 C.; theirs averaged 110.5 F. Mr. Siems has called your attention to the apparent differences in the initial levels of blood flow prior to treatment in the experiments in the two laboratories. I believe that equal temperature changes produced by treatment with either short wave or microwave diathermy will be accompanied with comparable vascular changes.

Finally, I wish to point out that the changes in blood flow as reported, whether a decrease or an increase, are of a low order. One must consider that a part of the change in blood flow is due to cutaneous dilatation. If one could correct his observed values for cutaneous flow changes, what would be his conclusions as to the effect of diathermy treatments on the blood flow through muscle? The changes in over-all blood flow during diathermy are of a low order and do not compare in magnitude with those resulting from slight activity or exercise and from the use of peripheral dilator drugs. I am not convinced from the evidence at hand that the alleged beneficial effects of diathermy treatments are related to changes in the blood flow through deep tissues. However, it must be admitted that this form of treatment might be much more effective in cases of blood vessel spasm or marked constriction than in cases of normal vessels. The experiments which have been discussed should be repeated, if possible, upon unanesthetized animals and by methods which permit the measurement of the blood flow through the deep tissues only.

Dr. William Bierman (New York): I should like to ask a question on a topic which Dr. Hines touched on in the very last sentence or two, as to the effect of the anesthesia itself when used in these exper-

imental animals upon the status of the sympathetic nerves and, therefore, on the blood flow?

Has anybody demonstrated that the sympathetic nerves control blood flow in the muscles of dogs? We have not found it to be so in the muscles of human beings. That finding, which we reported a goodly number of years ago, was supported by the work of Pickering in Sir Thomas Lewis' laboratory, indicating that the sympathetic nerves do not control the blood flow in muscles.

I should like to ask a third question of Dr. Worden. Does he think that the phenomenon he described of a gradual increase in temperatures for an initial period of twenty minutes, followed by a decline, is at all characteristic of this particular method of heating? My colleagues and I have observed as a universal occurrence in all methods of heating that there is a gradual increase to a maximum level (and in our own observations that level has been reached usually in between twelve and fifteen minutes) and then there is a decline to a plateau.

It would be interesting for some experimental workers to determine just what accounts for what we have referred to as a sort of "second wind" of the circulatory system, which seems to be able to handle that increased thermal energy.

Mr. Siems (closing): I should like first to answer Dr. Bierman's question regarding anesthesia. Pentobarbital anesthesia will certainly greatly increase peripheral blood flow, perhaps as much as two or three times its control level. However, this effect wears off in ten or fifteen minutes. It was with this fact in mind that we decided upon a one hour control period before instituting any heating, hoping by this means to eliminate any vasodilatory effect of the pentobarbital, or at least keep it at a minimum, since apparently its effect was in the initial stages of the anesthesia.

I have no wish to enter into a "cat and dog fight" with Dr. Hines on just why our results differ, or what are the possible reasons. The reason for presenting this paper here was simply to demonstrate that heat is heat. In other words, it makes no difference whether it be diathermy, short wave diathermy or microwave diathermy, the effect is essentially the same and the apparently limiting factor or positive factor is the amount of heat obtained.

I quite agree with Dr. Hines that we do not know where this increased blood flow is occurring, and, as taken up in our laboratory, we could conceive of no way of finding out.

Dr. Worden (closing): When tissues are heated locally by any method, the circulation would be expected to increase as the temperature increases. After a period of time the circulation may become so efficient that it carries off more heat from the tissues than is being put into the tissues.

When the method of heating is microwave diathermy, it has been shown by Leden and coworkers that during a twenty minute period of irradiation the circulation gradually increases and in some cases the peak is reached two or three minutes after the microwaves have been turned off.

When comparing the effect of microwaves and, for example, infra-red rays on the circulation, one might expect with microwave diathermy an increase in circulation of the deeper tissues relatively soon, because of good penetration and absorption. Infra-red radiation heats superficially, and the deep tissues receive heat secondarily by conduction; thus the increase in circulation of the deeper tissues might be comparatively slower.

Glaser