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ALMA J. MURPHY, R.P.T., M.S.
W. D. PAUL, M.D.
and
H. M. HINES, Ph.D.
IOWA CITY

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A COMPARATIVE STUDY OF THE TEMPERATURE CHANGES PRODUCED BY VARIOUS THERMOGENIC AGENTS *

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This report deals with a comparative study of the temperature changes produced by various thermogenic agents. Numerous reports have appeared concerning the thermogenic properties of short wave and microwave diathermy. Recent developments in engineering have made available radiations at several other wavelengths. In this study determinations were made of the temperature changes occurring in living and dead tissues as a result of irradiation with oscillating currents having a wavelength of 1,600 cm., 75 cm., 12.25 cm., 8.5 cm. and 3 cm. and the infrared portion of the electromagnetic spectrum. The temperatures were recorded at four different depths of tissue and compiled so as to determine the changes in temperature and the temperature gradients in the limb of living and of dead animals following irradiation with each wavelength.

Methods

This study was carried out on the hindlimbs of adult dogs ranging in weight from 13 to 19 Kg. The hair from the limbs was clipped closely in order to insure uniformity of insulation. Each live dog was utilized for a maximum of four irradiation treatments, and the limbs of dead dogs were irradiated only once. Two hours was allowed for temperature equilibration in the dead animals prior to irradiation. The temperatures of the tissues were determined by means of a thermocouple housed in a hypodermic needle and a Leeds-Northrup potentiometer.[1] The thermocouple needle was marked with enamel in order to determine accurately the desired depth of tissue. The temperatures were recorded at the external skin surface subcutaneous, 1.5 cm. and 3 cm. depths. All recordings were made in the same sequence in a small circular area and within a period of ninety seconds. The power output and mode of application required to produce the desired increase in tissue temperature were determined for each radiation frequency in preliminary trials. In the experiments in which both hindlimbs of an animal were used for study, a period of twenty to forty minutes were allowed to elapse between irradiation treatments.

1,600 Cm. Wavelength. — The cable of the short wave inductance diathermy generator was made into a pancake coil of three turns and separated from the animal's surface with a 2 cm. thickness of felt. A uniform reading of 12 units was set as the irradiation dose. A total of 32 experiments was carried out on living animals in which radiations were applied continuously for a period of twenty minutes and in which temperature measurements were made before and at the end of treatment. Eight experiments were made on living animals in which irradiation and temperature measurements were made in two consecutive periods of ten minutes each. Each animal in the dead tissue series was irradiated for two successive ten minute periods. Temperatures at the various levels were recorded before, at the termination of irradiation and every ten minutes thereafter until tissue temperatures had returned to approximately control levels.

75 Cm. Wavelength. — The 75 cm. generator delivered a power output of 8 kilowatts and was placed at a distance of 240 cm. from the animal. The surface of the animal except for one exposed limb was shielded from the radiations with copper screen. Experiments

* From the Department of Physiology and the Division of Physical Medicine, State University of Iowa.
* Read at the Twenty-Seventh Annual Session of the American Congress of Physical Medicine, Cincinnati, Sept. 7, 1949.
1. Tuttle, W. W., and Janney, C. D.: The Construction, Calibration and Use of Thermocouples for Measuring Body Temperatures, Arch. Phys. Med. 29:416 (July) 1948.

were carried out on 8 animals, 4 of which were anesthetized and 4 which were dead. The animals were irradiated for two consecutive periods of ten minutes each.

12.25 Cm. Wavelength. — A power output of 65 watts was employed in all of the 12.25 cm. microwave diathermy experiments. The 9 cm. director head was placed horizontally at a distance of 5 cm. from the surface of the limb. A total of 32 experiments was carried out on living animals in which the hindlimb was exposed to radiations for twenty minutes. In 6 experiments on living animals and 7 experiments on dead animals, the radiations were applied for two consecutive periods of ten minutes each and temperatures were measured at the end of each period.

8.5 Cm. Wavelength. — The director horn of the generator was placed at a distance of 20 cm. from the animal, and the generator was set to deliver 100 watts output. All animals were irradiated for two consecutive periods of ten minutes each. Fourteen experiments were carried out on living animals, and 7 experiments were made on dead animals.

3 Cm. Wavelength. — A 3 cm. pulsed wave generator with an average power output of 67 watts was employed at a distance of 40 cm. from the animal. The duration of the treatment periods and the interval of temperature measurements were the same as those employed in experiments with the 8.5 cm. wavelengths. A total of 16 experiments on living animals and 7 experiments on dead animals was made concerning the effects of 3 cm. radiations.

Infrared. — A 600 watt nonluminous infrared lamp was placed at a distance of 60 to 70 cm. from the limb to be treated. The limb was exposed to infrared radiation for two consecutive periods of ten minutes each. The pattern of temperature recording was the same as in the previously described experiments. A total of 14 experiments was carried out on living and 8 on dead animals.

Results

The temperature increases at the various depths resulting from irradiations with the several wavelengths are recorded in chart 1 and the table. It was found that greater increases in temperature occurred in superficial levels in 247 out of 266 experiments. In 240 out of a total of 266 experiments the least temperature increase was found at the 3 cm. depth. In the case of 75 cm. irradiations, the greatest increase in temperature occurred at the 1.5 cm. depth. However, irradiations with this wavelength resulted in greater elevations of temperature at the subcutaneous level than at the 3 cm. depth. The increases in temperature at the subcutaneous and 3 cm. levels are expressed as percentages of those found at the 1.5 cm. depth following irradiation with the several wavelengths (charts 2 and 3). From these data it can be seen that the shorter electromagnetic waves are relatively more effective for increasing the temperature in superficial tissues than in the deeper tissues and that the longer wavelengths are more effective for deep tissue heating. The same general relationship between wavelength and depth of heating was observed for both living and dead tissues. For all wavelengths studied in living animals, the greatest increment of temperature increase was found to occur during the first ten minutes of irradiation. The temperature increases in dead tissues were greater than those in living tissue following comparable periods of irradiation with all wavelengths. The temperature elevation in dead tissue exhibited a linear relationship to the time of irradiation. After irradiation, the temperatures of living tissues showed a tendency to have been equalized at all recorded depths. Only the tissues irradiated with the shorter wavelengths were inclined to show a higher temperature on the surface than in the deeper depths.

Comment

It is pertinent to point out that measurements of temperature increases alone are not necessarily indicative of the quantity of energy absorbed by tissues. A rise of temperature in any tissue merely indicates that the tissue in question has dissipated a smaller amount of heat to its internal and external

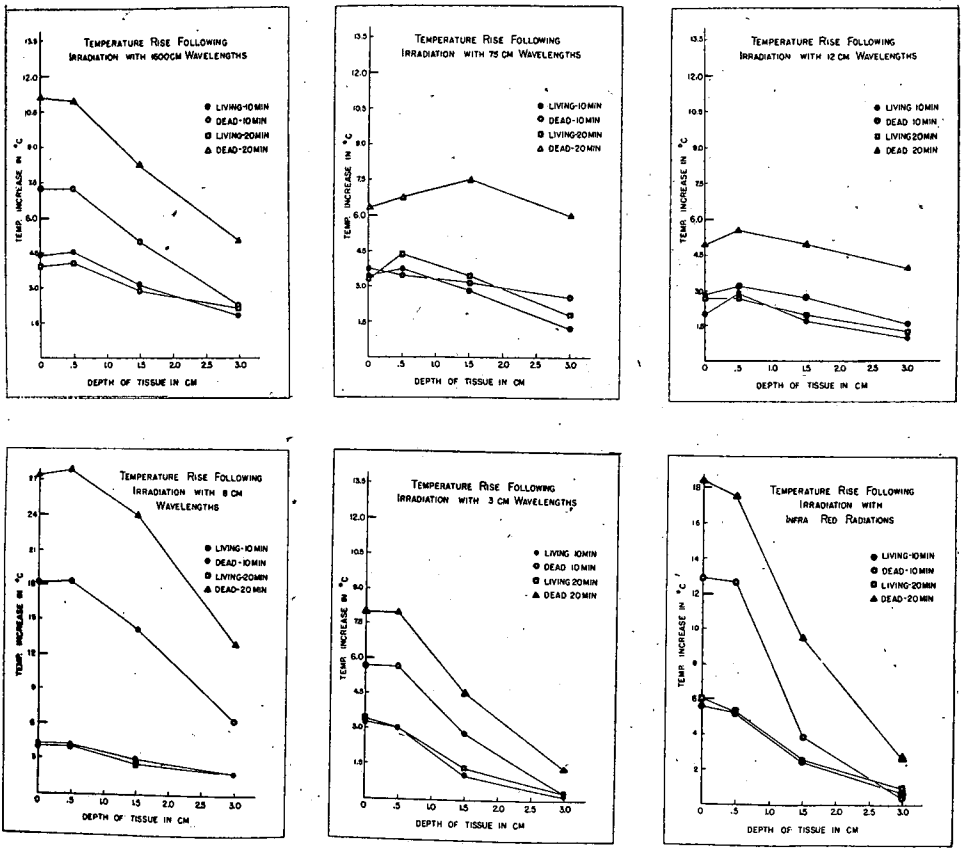

Chart 1. — Effect of irradiation on the temperature at various depths in the extremities of living and of dead dogs.

Temperatures of Living Tissues Irradiated with Electromagnetic Wavelengths.

Wavelength, Cm.	Tissue Depth, Cm.	Initial Temperature, °C.	Temperature Following Irradiation for 10 Min. °C	for 20 Min. °C.
1,600 cm.	Skin	36.9	41.7	40.7
	Subcutaneous	37.2	42.1	41.2
	1.5	38.6	42.0	41.5
	3	39.1	41.3	41.2
75	Skin	36.0	39.4	39.3
	Subcutaneous	36.2	39.9	40.6
	1.5	37.4	40.3	40.9
	3	38.6	39.8	40.4
12.25	Skin	37.0	39.5	39.7
	Subcutaneous	37.3	40.5	40.0
	1.5	38.6	40.6	40.6
	3	39.1	40.4	40.3
8.5	Skin	37.2	41.5	41.4
	Subcutaneous	37.5	41.7	41.5
	1.5	38.5	41.6	41.5
	3	39.4	41.3	41.4
3	Skin	36.8	40.1	40.2
	Subcutaneous	37.3	40.4	40.3
	1.5	38.4	39.5	39.8
	3	38.9	39.1	39.2
Infrared	Skin	37.1	42.7	43.1
	Subcutaneous	37.3	42.5	42.5
	1.5	38.7	41.1	41.2
	3	39.1	39.6	40.0

environment than that gained from local production and from its surroundings. The different levels of tissue depth at which the present temperature studies were made all present different gradient and vascular patterns. It is difficult, therefore, to determine where the greatest amount of energy absorp-

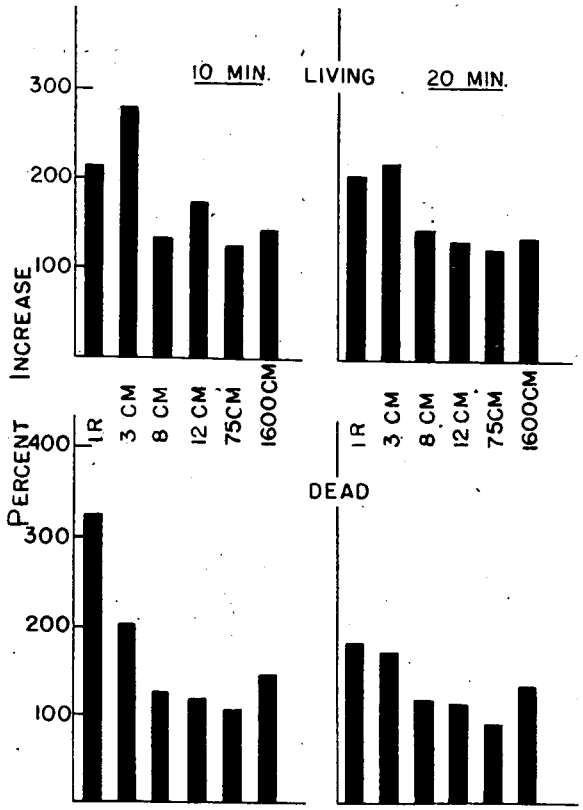

Chart 2. — Relative increases in temperature at the subcutaneous level expressed as percentages of those found at the 1.5 cm. level after irradiation with the several wavelengths.

tion occurs during the irradiation of living animals. This difficulty is emphasized by controversial reports concerning the nature of the changes in pattern of gradients resulting from irradiation with microwaves. Gersten and associates[2] reported 12.25 cm. microwaves cause a greater increase in the temperature of muscle than in skin or subcutaneous tissue. Other workers[3] have observed a greater rise in the superficial tissues than in the deeper layers during irradiation with this wavelength. Seguin[4] reported that greater superficial heating occurred with 3 cm. radiations than with 21 cm. waves. It is quite possible that much controversy could be avoided by more precise delineation of the terms "superficial" and "deep" tissues as well as standardization of experimental procedures.

Conclusions

The heating efficacy of six different wavelengths in living and dead animal tissues has been studied. Temperatures were recorded with a needle ther-

2. Gersten, J. W.; Wakim, K. G.; Herrick, J. F., and Krusen, F. H.: The Effect of Microwave Diathermy on the Peripheral Circulation and on Tissue Temperature in Man, Arch. Phys. Med. **30:7** (Jan.) 1949.

3. Osborne, S. L., and Frederick, J. N.: Microwave Radiations: Heating of Human and Animal Tissues by Means of High Frequency Current with Wavelength of Twelve Centimeters (the Microtherm), J. A. M. A. **137:1036** (July 17) 1948. Rae, J. W.; Herrick, J. F.; Wakim, K. G., and Krusen, F. H.: A Comparative Study of the Temperatures Produced by Microwaves and Short Wave Diathermy, Arch. Phys. Med. **30:199** (April) 1949. Horvath, S. M.; Miller, R. N., and Hutt, B. K.: Heating of Human Tissues by Microwave Radiation, Am. J. Med. Sc. **216:430** (Oct.) 1948.

4. Michaelis, M.: Report of an International Congress: Electromagnetic Waves, Brit. J. Phys. Med. **12:38** (March-April) 1949.

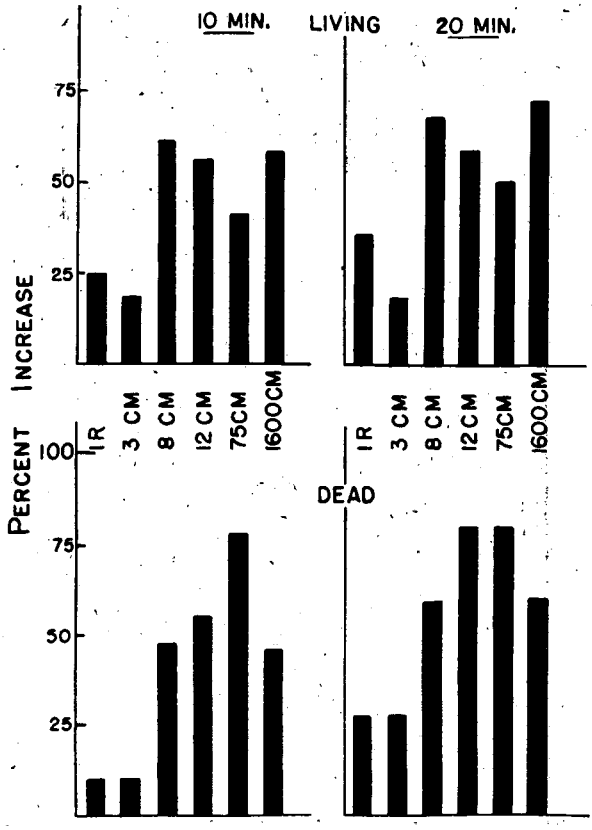

Chart 3. — Relative increases in temperature at the 3 cm. level expressed as percentages of those found at the 1.5 cm. level after irradiation with the several wavelengths.

mocouple at the surface, subcutaneous, 1.5 cm. and 3 cm. depths following two successive ten minute periods of irradiation.

The data collected relative to the temperature elevation following electromagnetic irradiation seem to justify the following conclusions:

1. Temperature elevations occurred when living and dead tissues were irradiated with 1,600 cm., 75 cm., 12.25 cm., 8.5 cm., 3 cm. and infrared rays.

2. A greater temperature elevation occurred in the superficial tissues than in the deeper tissues when irradiation was carried out with high frequency electromagnetic waves.

3. The increment of temperature change was greater during the first ten minute period of irradiation of living tissue than during the second ten minute period.

4. High frequency irradiation caused a greater increase in temperature in dead tissue than in living tissue during comparable heating periods.

5. The ratio between the temperature increase at 3 cm. depth to that at the 1.5 cm. depth is greater for the longer wavelengths than for the shorter wavelengths.

6. The ratio of the temperature increase at the subcutaneous level to the temperature increase at 1.5 cm. level is greater for the shorter wavelengths than for the longer wavelengths.

Discussion

Dr. Frederic T. Jung (Chicago): The authors have focused attention on a single variable, namely, the wavelength, and they have studied the influence of its variations upon the dependent variable, namely, the amount of heat liberated. They have tried to keep all other factors constant.

The advantages of working in this way are not widely enough appreciated, and, as a matter of fact, in clinical research it is

not always possible to control the other factors as well as they have been controlled in this instance. Also, the range over which the independent variable is allowed to move is often so narrow that conclusions are misleading. Within a narrow range the relation of the two variables may be linear, while in a broader range the relation may be seen to be curvilinear and to exhibit a minimum or maximum.

In the present instance it appears that within the range studied by the authors there lies an optimum wavelength. If that is correct, exploration of shorter and longer wavelengths cannot be expected to yield important new results, and an effort should be made to locate the optimum more precisely.

However, in dealing with a variety of diathermy apparatus it is hard to make sure that the wattages of the output are comparable, and the authors have noted this fact. Both the users and the manufacturers of diathermy apparatus would be glad to see somebody develop a reliable method of measuring and controlling the output.

Miss Murphy (closing): Dr. Jung's implied question concerning the effectiveness of a specific wavelength for optimal heating of tissues cannot be answered from this investigation. There is a tendency for the shorter wavelengths to heat the superficial tissues to a greater extent than do the longer wavelengths and the longer wavelengths to heat the deeper tissues to a greater extent than do the shorter wavelengths. The distinction between longer and shorter wavelengths cannot be made specifically from this study.

A question has been raised as to why temperatures were not recorded deeper than 3 cm. in the tissues. The leg of the experimental animal was not thick enough for the recording of temperature measurements at deeper depths. Moreover, additional temperature measurements would have been influenced by the greater time necessary to record a longer sequence of temperature readings.