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TEMPERATURE DISTRIBUTIONS AS PRODUCED BY MICROWAVES IN SPECIMENS UNDER THERAPEUTIC CONDITIONS*

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A NUMBER of physiological reactions result from an elevation of local tissue temperature in live subjects. Many of these effects are considered to be of therapeutic value. The direct heating of an area results in more numerous and more intense therapeutic reactions than is the case when distant parts are heated and the reactions are reflex in nature.

The therapeutic effects of a modality depend mainly upon the pattern of temperature distribution produced in the tissues. When selecting a modality for treatment purposes it would be desirable to choose one which develops a temperature distribution with its peak temperature in the area to be treated. Then, varying the dosage of the energy applied, the temperature could be maintained within the therapeutic range without producing an excessive heating effect in other areas.

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The following are factors which determine the resultant temperature distribution:

1. The pattern of relative heating, which is an expression of the energy available for heat production. This is determined by the dielectric constants and conductivities of the tissues being traversed by the microwave energy.

2. The value of the specific heat of each tissue layer, which determines the actual temperature increments. Thus it can be seen that the temperatures developed in the various tissues by microwaves are the product of the pattern of relative heating and the characteristic properties of the tissues being radiated.

3. The thermal conductivity, which modifies the actual temperature increments over a period of time. For this reason the "instantaneous" temperature distribution might appear to be quite different from the one resulting from exposure of the same tissues over a period of time.

4. Biological factors, such as blood flow, which have as yet an undetermined effect on the resultant temperature distribution.

The objective of this series of investigations was to determine the patterns of relative heating and the resultant temperature distributions produced by microwave diathermy at frequencies of 2,450 and 900 megacycles (mc.).

DISTRIBUTIONS IN SIMPLE SPECIMENS

Previous investigators measured the dielectric constants and the conductivity or specific resistance of tissues at various microwave frequencies (Herrick *et al.*, 1950; England, 1950). Using these data, Schwan and his co-workers (1958) and Cook (1951) calculated the patterns of relative heating produced in tissues at various frequencies. They concluded that frequencies at 900 mc. or lower would be more effective in heating the musculature and deeper structures than is the frequency of 2,450 mc. which is now used for therapy. These calculations were based on the assumption that the tissue layers have plane and parallel tissue interfaces with an abrupt change of the characteristic properties from one layer to the other. Since few of the anatomical structures treated fulfil these specifications, it seemed worth while to determine if the calculated distribution of relative heat actually described the heating pattern obtained in an anatomical specimen.

Thighs of freshly slaughtered pigs were used as specimens, which consisted of skin, subcutaneous fat, and muscle. Essentially all microwave energy remaining after traversing the skin, the subcutaneous fat, and the interfaces was absorbed within the thick muscle layer. Frequencies studied were 2,450 and 900 mc. Wave guides were used for all measurements at both frequencies in order to provide a uniform and measurable field distribution for the experimentation and also to retain the total energy output from the generators without radiation losses. The wave guides were rectangular, and each had a slotted centre section which permitted measurements of the distribution of power throughout the specimen by using a bolometer probe and a microwave power meter.

In addition, the actual temperature distribution throughout the specimen was monitored continuously by means of thermistor beads embedded in the tips of silver-plated, stainless steel hypodermic needles and a multiple-channel temperature recording instrument (Visicorder). The needles were arranged parallel to the magnetic field vector in order to reduce the induction of high-frequency currents which might heat the thermistor bead.

The theoretical distribution of relative heating was calculated for each specimen using measurements of the dielectric constant and the specific resistance of the tissues, assuming plane parallel boundaries between the different layers of the specimen (Figs. 1 and 2). Then the actual pattern of relative heating was obtained for the same specimen by direct measurements of the field distribution along the axis of the specimen (Figs. 3 and 4). A comparison of the results of these procedures showed that the findings were essentially the same in either case. This similarity

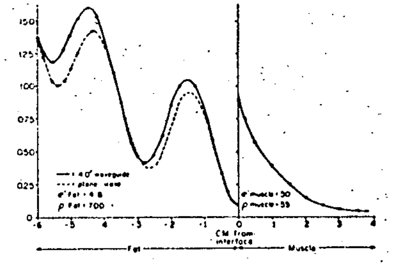

FIG. 1.—Relative heat calculated from dielectric constants and specific resistances (2,450 mc.).

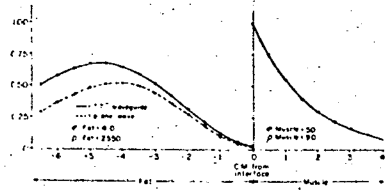

FIG. 2.—Relative heat calculated from dielectric constants and specific resistances (900 mc.).

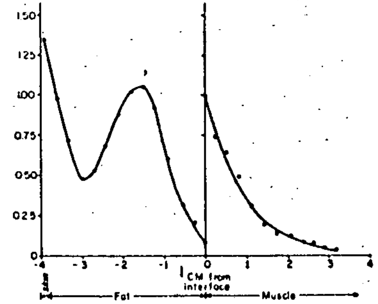

FIG. 3.—Relative heat calculated from field distribution (2,450 mc.).

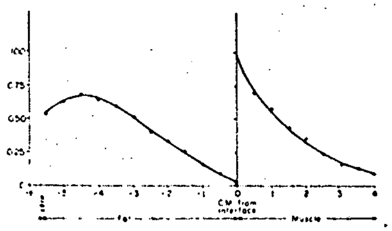

FIG. 4.—Relative heat calculated from field distribution (900 mc.).

indicates that the geometry of the tissue interface in the actual specimen is for all practical purposes essentially plane and parallel with an abrupt change of the dielectric properties from one tissue to the other.

In another series of experiments the temperature distributions resulting from the patterns of heating were studied (Figs. 5 and 6). Because of the comparatively low specific heat and thermal conductivity of subcutaneous fat, it could be anticipated that relatively high temperature values would be obtained in the subcutaneous fat during exposure to microwaves. This was found to be the case when the specimen was exposed to the energy for short periods of time. However, the temperature distributions studied in these experiments indicate that the depth of penetration of the microwave energy into the tissues is considerably greater at the frequency of 900 mc. than at 2,450 mc. Also, it is apparent that relatively more energy is converted into heat in the subcutaneous fat at the high frequency than at the low frequency. In other words, relatively more heat is developed in the muscle tissue at the low frequency than at the high frequency.

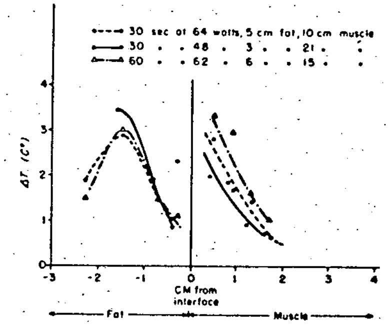

FIG. 5.—Temperafure distribution (2,450 mc.).

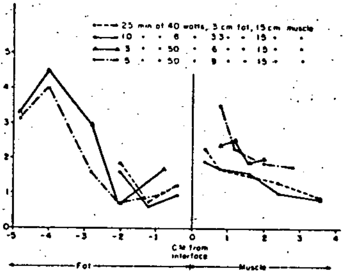

FIG. 6.—Temperature distribution (900 mc.).

From the therapeutic point of view, it seems probable that microwaves at the frequency of 900 mc. would be more effective in heating the deeper tissues than would be those at 2,450 mc.

If the specimen was exposed over a longer period of time so that heat conduction was allowed to occur, it was observed that the temperature readings taken near the fat–muscle interface were somewhat higher in the fat and lower in the muscle than could be anticipated from the pattern of heating (Fig. 7). This phenomenon was probably due to heat conduction from the hotter to the cooler areas. Thus heat conduction, if allowed to occur, has a tendency to even out the temperature distribution over a period of time.

With the use of either frequency under therapeutic conditions it appears that a relatively high, if not the highest, temperature would be obtained in the subcutaneous tissues in an obese person. However, in the case of a patient with a moderate amount of subcutaneous fat (2 cm. or less) there is a decided difference between the results of the two frequencies. The highest temperature would be obtained in the musculature if the patient were treated with 900 mc., whereas the highest temperature would still occur in the subcutaneous fat with 2,450 mc. Therefore, it is evident that the frequency of choice for deep heating purposes would be of the order of 900 mc. or lower.

PATTERNS OF HEATING AND TEMPERATURE DISTRIBUTIONS IN GEOMETRICALLY COMPLEX SPECIMENS CONTAINING BONE

In the next phase of these studies an attempt was made to obtain information on temperature distributions in specimens with more complex geometry, including bone. In this case the microwaves were applied with the open end of the wave guide flush against the skin surface of the specimen. This technique of application results in some divergence of the microwave beam outside the wave guide with a corresponding decrease in the intensity along the central axis of the field (Cook, 1951).

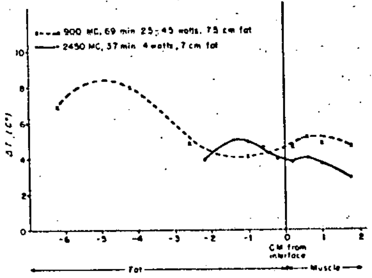

FIG. 7.—Temperature distribution resulting from a longer exposure (2,450 and 900 mc.).

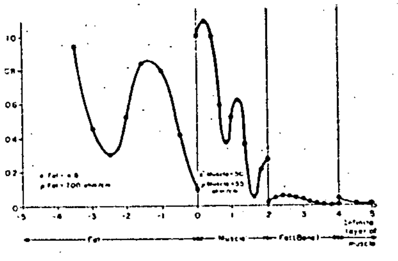

FIG. 8.—Relative heat calculated from dielectric constants and specific resistances (2,456 mc.).

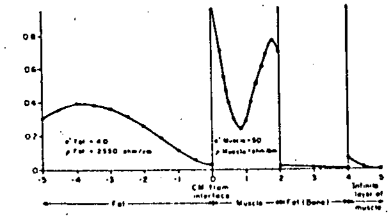

FIG. 9.—Relative heat calculated from dielectric constants and specific resistances (900 mc.).

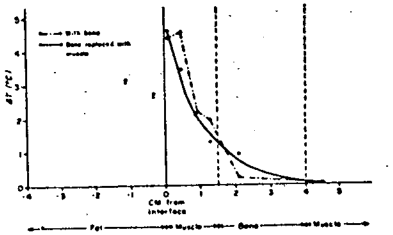

FIG. 10.—Temperature distribution in specimens with and without bone.

First, the patterns of relative heating for the frequencies of 2,456 and 900 mc. were calculated from the known dielectric constants and specific resistivities of the tissues for a specimen consisting of subcutaneous fat, muscle, and bone and muscle. The dielectric data for bone were not available; therefore the data for fat were substituted in this calculation, since Schwan (1958) has stated that the dielectric constant and specific resistivity of bone should be similar to those of fat. The results of these calculations are shown in Figs. 8 and 9.

Temperature distributions were then measured during exposure of specimens consisting of skin, subcutaneous fat, muscle, and bone or muscle. The specimen was exposed once to microwaves with the bone in the specimen, and then the specimen was exposed a second time after replacing the bone with muscle tissue. With 2,456 mc. the specimen without bone showed an exponential decrease in the temperature distribution throughout the muscle tissue which conformed to the calculated patterns of relative heating. When the same specimen was exposed with the bone inserted in the specimen, an irregular rise of temperature occurred in front of the bone (Fig. 10). This result seemed to be due to reflection at the muscle–bone interface and resembled the calculated pattern of heating resulting from reflection at the muscle–bone interface.

At the 900 mc. frequency no evidence could be found indicating any reflection occurring at the muscle–bone interface. At this frequency curves were similar throughout the muscle layer in the area in front of the bone whether the bone was in place or removed.

The temperature distributions resulting from exposure of specimens with bone *in situ* to frequencies of 900 mc. did not conform to the calculated pattern of heating, since there was no rise of temperature in the area in front of the bone. This discrepancy could be explained on the basis of wave length and bone diameter relationships. At the frequency of 2,456 mc. the wave length is smaller than the bone diameter, whereas the 900 mc. wave length in muscle is considerably larger than the bone diameter. This would result in a less pronounced reflection of the wave at the lower frequency.

Findings also indicated that the temperature increments recorded behind or inside the bone were much less than the increments occurring at the same spacings in muscle tissue during exposure to either frequency (Table I). Temperatures recorded behind the bone were always lower than those in front (Table II).

It is felt that the reflection at the bone–muscle interface from the exposure of the 2,456 mc. could possibly lead to the production of hot spots in that area. Worden and co-workers (1948) reported the occurrence of burns in the form of blebs over the femurs of dogs after exposure to microwaves at 2,450 mc. This could have been the result of the energy reflected at the bone–muscle interface.

With either frequency the results indicate that little energy penetrates bone. Thus, in order effectively to heat major joint structures it is apparently necessary to expose them from all accessible aspects.

TABLE I

RISE OF TEMPERATURE AFTER EXPOSURE TO MICROWAVES AT FREQUENCIES OF 2,456 AND 900 MEGACYCLES AS RECORDED BEHIND BONE AND IN SAME LOCATION AFTER REPLACEMENT OF BONE WITH MUSCLE

Frequency 2,456 mc.		Frequency 900 mc.	
With Bone	Bone Replaced With Muscle	With Bone	Bone Replaced With Muscle
0·5° C.	0·7° C.	1·1° C.	2·1° C.
0·4° C.	0·5° C.	1·1° C.	2·3° C.
0·5° C.	0·7° C.	1·7° C.	2·7° C.
0·2° C.	0·5° C.	1·5° C.	2·7° C.

TABLE II

DIFFERENCE IN TEMPERATURES AS INDICATED BY MEASUREMENTS IN FRONT OF AND BEHIND BONE AFTER EXPOSURE TO MICROWAVES AT FREQUENCIES OF 2,456 AND 900 MEGACYCLES

Frequency 2,456 mc.	Frequency 900 mc.
6·4° C.	5·1° C.
4·6° C.	1·7° C.
9·2° C.	3·6° C.
6·0° C.	2·4° C.

TEMPERATURE DISTRIBUTIONS PRODUCED BY COMMERCIAL APPLICATORS

After completing the various studies with specimens within a wave guide and in free space by exposures to microwaves at the frequencies of 2,456 and 900 mc., it was felt that studies should be made of specific temperature distributions produced by commercially available directors used with the 2,456 mc. microwave unit employed in clinical application. This was necessary in order to determine whether or not the difficulties encountered in heating the deep tissues could be overcome by the effect of the applicator. Commercially available directors are designed to beam the microwave energy, and this effect might cause a concentration of energy in the deeper tissue layers and thus a relatively higher rise of temperature there.

It was felt that applicator design might explain the heating effects reported by Gersten *et al.* (1949), Rae *et al.* (1949), and Engel *et al.* (1950). These workers found that under certain conditions the higher temperatures throughout the distribution occurred in the musculature rather than in the subcutaneous fat during exposure to microwaves at 2,456 mc. with commercial applicators. However, it is conceivable that thickness of the fat layer rather than applicator design was the critical factor in producing relatively greater temperature increments in the depths of the tissues. These workers used the hind legs of dogs and the forearms of human beings in their studies. In both cases the subcutaneous fat is relatively thin, usually measuring only a few millimetres in depth. On the basis of our work using wave guides, one might expect this kind of result under these conditions. Even so, these results would not seem to apply to most clinical applications of microwaves, since areas exposed usually have a subcutaneous fat layer of 1 cm. or more in thickness. Thus, under the usual therapeutic conditions, an undesirable and excessive amount of heating of the subcutaneous fat would result.

The specific characteristics of the three most commonly used directors in clinical application were studied. The "C" director, with a corner type of reflector, is designed to produce, on cross-section, an oval-shaped field with an area of maximum intensity in the centre of the field. The "A" director utilizes a hemispherical reflector approximately 9·3 cm. in diameter, and is designed to produce, on cross-section, a circular, doughnut-shaped pattern with a reduced amount of intensity in the centre of the field. The "B" director has essentially the same construction as the "A", with the exception that the reflector is approximately 15·3 cm. in diameter and the resultant field correspondingly larger.

Commercially available microtherm units operating at a frequency of 2,456 mc. were used for these experiments.* Specimens taken from the thighs of freshly slaughtered pigs were used as in previous studies. The specimens consisted of skin, subcutaneous fat of various thicknesses, and a thick layer of muscle tissue which absorbed all the remaining microwave energy. Temperatures were recorded during each experiment through the use of thermistor probes connected to a multichannel recording instrument (Visicorder). To rule out the possibility of inaccurate readings due to radiation pick-up the needles were first positioned and exposed to microwaves in air. No temperature increase was developed. The specimens were scanned in such a manner as to study the heating pattern of the director through the depths of the tissues as well as in the lateral boundaries of the field. In order to determine the applicator–specimen spacing which would yield the most accurate and meaningful temperature measurements, a series of studies was carried out with the director flush against the surface, 2 cm. above the surface, and 3 cm. above the surface. Another factor varied in this series was the thickness of the fat layer of the specimen. The following thicknesses were used: 0·7–1·5 cm., 2 cm., and 3 cm. The studies indicated that the best position for placement of the director was on the surface of the specimen, because this spacing developed relatively greater temperature increments in the muscle layers (Figs. 11–13). However, without exception, the highest temperatures occurred in the subcutaneous fat in all specimens studied.

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* Raytheon and Burdick Corporation.

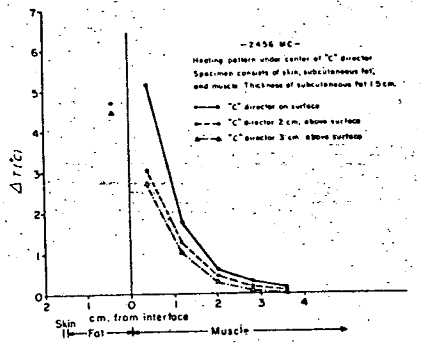

FIG. 11.—Heating pattern under centre of "C" director at spacings of 0, 2, and 3 cm. from surface (subcutaneous fat thickness of 0·7–1·5 cm.). (2,456 mc.)

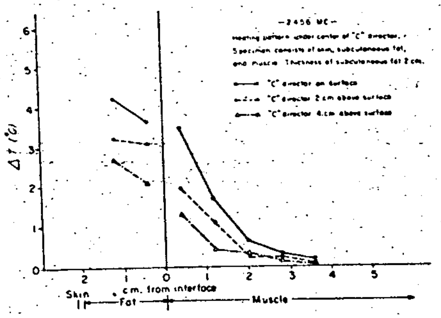

FIG. 12.—Heating pattern under centre of "C" director at spacings of 0, 2, and 3 cm. from surface (subcutaneous fat thickness of 2 cm.). (2,456 mc.)

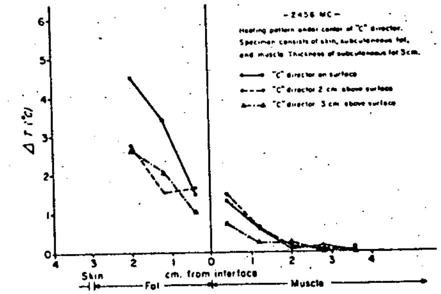

FIG. 13.—Heating pattern under centre of "C" director at spacings of 0, 2, and 3 cm. from surface (subcutaneous fat thickness of 3 cm.). (2,456 mc.)

The first series of experiments was conducted with the "C" director located directly on the surface of the specimen. The method of scanning the field with thermistors is shown in Figs. 14–16. In all cases the greatest rise of temperature occurred in the subcutaneous fat directly under the centre of the applicator (Figs. 17–19). The field distribution was similar to the beam shape as described by Rae *et al.* (1949).

In the second series the temperatures produced by the "A" director were measured. Figs. 20–22 show the method of scanning the field. Again the greatest increments were found in the subcutaneous fat (Figs. 23–25), and again the temperature distribution was similar to the pattern of intensity of the beam, with peak temperatures in a ring approximately 6 cm. in diameter (Rae *et ál.*, 1949). An exception to this pattern was noted, however, in measurements taken in the most superficial subcutaneous fat layers, for the peak temperatures were found near the centre of the applicator. This could be attributed to a higher concentration of energy near the antenna rod.

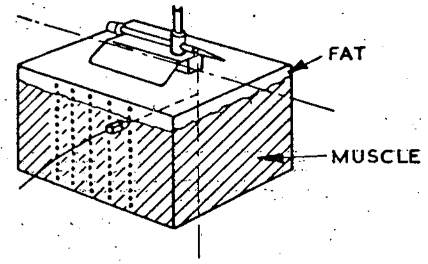

FIG. 14.—Relationship of thermistor needles to "C" director (oblique view).

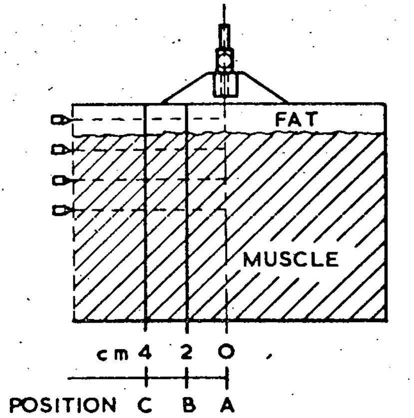

FIG. 16.—Relationship of thermistor needles to "C" director (lateral view).

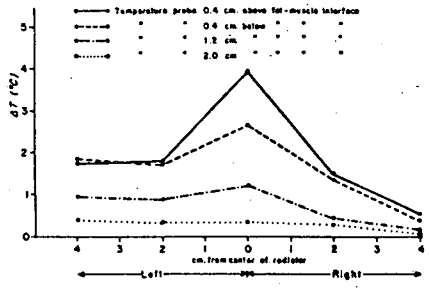

FIG. 18.—Temperature distribution with "C" director as measured parallel to and 2 cm. in front of the long axis of the dipole antenna at various depths of the tissues: Position B. (2,456 mc.)

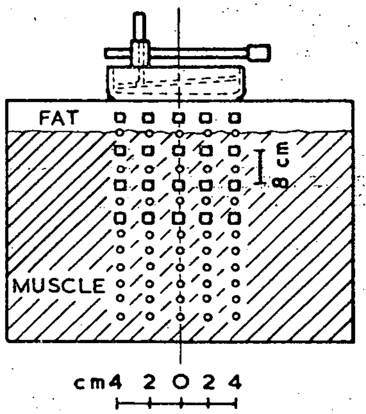

FIG. 15.—Relationship of thermistor needles to "C" director (anterior view). Squares indicate position of needles.

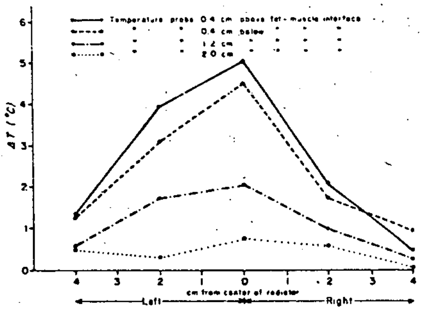

FIG. 17.—Temperature distribution with "C" director as measured parallel to and directly beneath the dipole antenna at various depths of the tissues: Position A. (2,456 mc.)

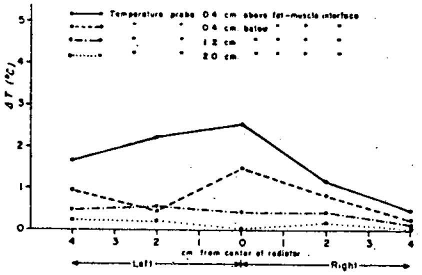

FIG. 19.—Temperature distribution with "C" director as measured parallel to and 4 cm. in front of the long axis of the dipole antenna at various depths of the tissues: Position C. (2,456 mc.)

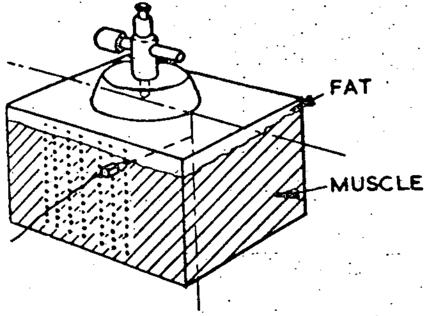

FIG. 20.—Relationship of thermistor needles to "A" director (oblique view).

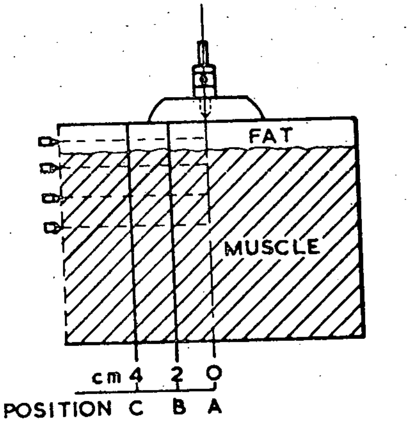

FIG. 22.—Relationship of thermistor needles to "A" director (lateral view).

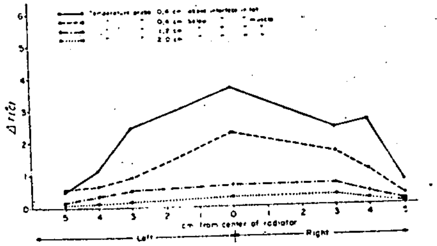

FIG. 24.—Temperature distribution with "A" director as measured at various depths of the tissues in a plane parallel and 2 cm. anterior to a plane going through the diameter of the reflector: Position B. (2,456 mc.)

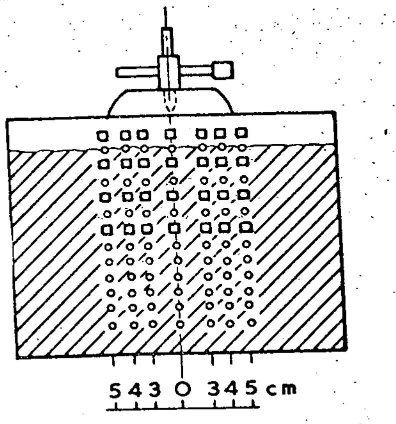

FIG. 21.—Relationship of thermistor needles to "A" director (anterior view). Squares indicate position of needles.

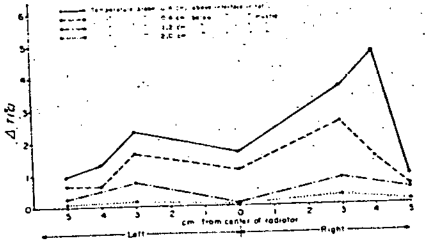

FIG. 23.—Temperature distribution with "A" director as measured at various depths of the tissues in a plane going through the diameter of the reflector: Position A. (2,456 mc.)

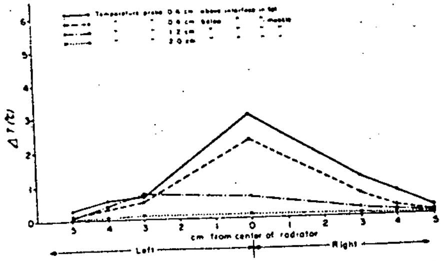

FIG. 25.—Temperature distribution with "A" director as measured at various depths of the tissues in a plane parallel and 4 cm. anterior to a plane going through the diameter of the reflector: Position C. (2,456 mc.)

The results with the "B" director were similar to those obtained with the "A" director, with the following exceptions: (1) with the "B" director there was a larger area of maximal temperature rise, leaving a distance of only 3–4 cm. from the proximal border of this area to the centre of the field; (2) peak temperatures were never observed in the centre of the field in any area of the specimen. The temperature distribution always followed the intensity pattern described by Rae *et al.* (1949).

In all the experiments the resulting temperature distributions were found to be consistently asymmetrical. The possible causes for this lack of symmetry, such as reflection at various tissue interspaces and minor variations in the alignment of the director, could not be ascertained.

SUMMARY

Temperature distributions produced by microwaves in specimens suggest the following conclusions of therapeutic significance:

1. With either microwave frequency, the radiation of tissue areas having a subcutaneous fat layer of 4 cm. or more results in a temperature distribution having its peak temperatures in the subcutaneous fat.

2. The microwave frequency of choice would be 900 mc. or lower for the application of microwaves to a tissue area containing a moderate amount of subcutaneous fat (i.e. approximately 2 cm.). This would produce the highest temperatures in the musculature, and in turn would increase the conductive heating effects to the deeper muscle layers.

3. A heating pattern indicative of energy reflection at the muscle–bone interface was observed during exposures to microwaves at 2,456 mc. It is conceivable that this reflection could lead to the development of "hot spots" in the tissues. This hazard could not be demonstrated under experimental conditions at the 900 mc. frequency.

4. Temperature measurements taken behind bone were consistently lower than those taken in the same area when bone was replaced by muscle tissue during exposure to both 2,456 and 900 mc. This would indicate that adequate heating of bone structures and joints could be achieved only by exposing the joint from all accessible areas.

5. Microwaves at a frequency of 2,456 mc., beamed from the commercially available directors, produce a therapeutically undesirable increase in temperature in the subcutaneous fat.

Further investigations are necessary in order to determine whether or not the temperature distributions found in specimens are altered to any significant degree under therapeutic conditions when the circulatory system and other related physiological factors are intact and functioning.

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remissions of skin and joint lesions. Severe skin and nail lesions frequently occurred. The feet were more often involved than the hands.

Pain was a remarkably inconspicuous symptom in half of the cases.

Radiologically there was massive osteolysis with tapering of phalanges and metacarpals or metatarsals, with concomitant new bone formation and bony ankylosis of small joints. Sacro-iliac changes occurred frequently.

Brunner

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REFERENCES

AVILA, R., PUGH, D. G., SLOCUMB, C. H., and WINKELMANN, D. K. (1960) *Radiology*, **75**, 691.
BAKER, H., GOLDING, D. N., and THOMPSON, M. (1963) *Ann. intern. Med.*, **58**, 909.
BALL, J. (1952) *Ann. rheum. Dis.*, **11**, 97.
BUCKLEY, W. R., and RALEIGH, R. L. (1959) *New Engl. J. Med.*, **261**, 539.
FAWCITT, J. (1950) *Brit. J. Radiol.*, **23**, 440.
FORESTIER, J., JACQUELINE, F., and ROTES-QUEROL, J. (1956) *Ankylosing Spondylitis*, p. 207. Charles C. Thomas, Springfield, Ill.
GORHAM, L. W., and STOUT, A. P. (1955) *J. Bone Jt Surg.*, **37A**, 985.
JUNGMANN, H. (1944) *Brit. J. Radiol.*, **17**, 383.
MCEWEN, C., ZIFF, M., CARMEL, P., DITATA, D., and TANNER, M. (1958) *Arthr. and Rheum.*, **1**, 481.
MARIE, P., and LÉRI, A. (1913) *Bull. Soc. méd. Hôp. Paris*, **36**, 104.
NIELSEN, B., and SNORRASON, E. (1946) *Acta radiol. (Stockh.)*, **17**, 607.
SHARP, J. S. (1957) *Brit. med. J.*, **1**, 975.
SHERMAN, M. S. (1952) *J. Bone Jt Surg.*, **34A**, 831.
SHLIONSKY, H., and BLAKE, F. G. (1936) *Ann. intern. Med.*, **10**, 537.
STRÖM, S. (1921) *Acta radiol. (Stockh.)*, **1**, 21.
WRIGHT, V. (1959) *Amer. J. Med.*, **27**, 454.
——— (1961) *Ann. rheum. Dis.*, **20**, 123.

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REFERENCES

COOK, H. F. (1951) *Brit. J. appl. Physics*, **2**, 295.
ENGEL, J. P., HERRICK, J. F., WAKIM, K. G., GRINDLAY, J. H., and KRUSEN, F. H. (1950) *Arch. phys. Med.*, **31**, 453.
ENGLAND, T. S. (1950) *Nature (Lond.)*, **166**, 480.
GERSTEN, J. W., WAKIM, K. G., HERRICK, J. F., and KRUSEN, F. H. (1949). *Arch. phys. Med.*, **30**, 7.
HERRICK, J. F., JELATIS, D. G., and LEE, G. M. (1950) *Fed. Proc.*, **9**, 60.
RAE, J. W., HERRICK, J. F., WAKIM, K. G., and KRUSEN, F. H. (1949) *Arch. phys. Med.*, **30**, 199.
SCHWAN, H. P. (1958) "Biophysics of Diathermy" in *Therapeutic Heat*, ed. S. Licht, Vol. II. Elizabeth Licht, New Haven, Connecticut.
WORDEN, R. E. (1948) *Arch. phys. Med.*, **29**, 751.