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EXPERIMENTAL LENTICULAR OPACITIES PRODUCED BY MICROWAVE IRRADIATIONS *

A. W. RICHARDSON, M.S.

T. D. DUANE, M.D.

and

H. M. HINES, Ph.D.

IOWA CITY

While the development of cataract by means of irradiations is not new, having been established by various investigators (Bellows),¹ work in the past has been concerned chiefly with the effects of infra-red, ultraviolet and roentgen irradiations. In 1926, in a survey of work in these fields, Duke-Elder² suggested that future work might disclose many other portions of the spectrum to have pathogenic effects on the eye, if the energy were of sufficient magnitude.

Sinus disorders have been treated extensively by the use of short wave diathermy for a number of years. Such irradiations have proved to be safe when used as prescribed. Montreiff, Coulter and Holmquest³ irradiated the eyes of dogs in vivo with diathermy, 600 ma., for fifteen minutes and reported temperature rises of 6.54 and 6.98 degrees Centigrade in the anterior chamber and posterior segment. This dosage was considered to be safe.

With the production of a new microwave generator by Raytheon which propagates 12.25 cm. waves, a new band of the electromagnetic spectrum has been offered for medical therapy. Krusen, Herrick, Leden and Wakim,⁴ found that these microwaves effectively heated the highly vascularized musculature of the dog. Osborne and Frederick⁵ reported that temperatures were adequately induced in the highly vascularized tissues of both human subjects and dogs when standard testing procedures were followed. In acute experiments exposing the eye of the dog to an output of 75 to 100 watts at a distance of 5.08 cm. the temperature of the vitreous was increased to an average of 41 C. (maximum 44.4 C.). On examination immediately following the irradiations, no pathologic effects were found in the eyes.

The studies of these groups have been concerned predominantly with temperature increases induced in body tissues, including the eye, and in the immediate changes produced. The purpose of our observations was to study more thoroughly both the immediate and the delayed effects of microwave irradiations upon the eye. It was thought that since the center of the eye is a relatively avascular area it might be less capable of heat dissipation than other more vascular tissues. We have found that this form of radiation is highly productive of experimental lenticular opacities.

Procedure

The Raytheon 12.25 cm. microwave generator model CMD4 was used throughout the experiments. This machine delivers a peak output of 125 watts, but in all cases an output of 100 watts was employed with use of the rectangular corner type wave

* From the Department of Physiology, College of Medicine, State University of Iowa.

1. Bellows, J. G.: *Cataract and Anomalies of the Lens*, St. Louis, C. V. Mosby Company, 1944, chap. 7.

2. Duke-Elder, W. S.: *Pathological Action of Light Upon the Eye*, *Lancet* 1:1188, 1926.

3. Montreiff, W. F.; Coulter, J. S., and Holmquest, H. J.: *Experimental Studies in Diathermy Applied to the Eye and Orbit*, *Am. J. Ophth.* 15:194, 1932.

4. Krusen, F. H.; Herrick, J. F.; Leden, U., and Wakim, K. G.: *Preliminary Report of Experimental Studies of the Heating Effect of Microwaves*, *Proc. Staff Meet., Mayo Clin.* 15:104, 1947.

5. Osborne, S. L., and Frederick, J. N.: *Microwave Radjations*, *J. A. M. A.* 137:1036, 1948.

director. Care was exercised to avoid any undesirable standing waves in the coaxial cable which might be produced by large metal objects or other artefact-initiating conditions. Animals were irradiated on wood laboratory tables, while excised eyes were irradiated on rectangular Plexiglas pedestals. These precautions were taken to insure consistent optimal temperature measurements.

During and after exposures, temperature measurements were taken by means of iron-constantan thermocouples housed in hypodermic needles as described by Tuttle and Janney.⁶ Potentials were recorded on a Leeds and Northrup type 8662 potentiometer, and temperature measurements were calibrated with a bureau of standards thermometer.

In order to eliminate the possibility that the temperature readings might be measurably affected by the presence of the thermocouple in the field of microwaves other than from tissue temperature per se, we irradiated one group of animals with the thermocouple in situ and compared this with another group in which the thermocouple was introduced immediately after the irradiation period. There was no significant difference between the temperatures recorded in these two groups of experimental eyes.

When intact eyes were irradiated throughout the experiments, 3 to 5 Kg. albino rabbits were employed in vivo and post mortem. Rabbits exposed in vivo were anesthetized with Nembutal or urethane. Such animals received drops of atropine and Pontocaine previous to exposure in order to minimize irritability and assure a uniform size of the pupil. In experiments upon excised eyes, both normal mongrel dogs and albino rabbits were used.

The wave director was alined directly on and at a right angle to the optic axis in all cases, and the distance was measured from the plastic director housing to the cornea. Internal eye temperatures were taken by inserting a thermocouple into the posterior segment until the tip rested in the vitreous at the posterior pole of the lens.

These animals were maintained on sufficient water and Purina laboratory food during the experiments to insure an adequate diet. They were kept in well ventilated rooms moderately lighted with indirect sunlight. The eyes were inspected by use of a hand slit lamp and ophthalmoscope prior to irradiation, immediately after and at daily intervals.

Results

Excised Eyes; Rabbits and Dogs. — This series of observations was designed to study any lenticular changes resulting from irradiation upon an isolated, and thus avascular, system. When the temperatures of the excised eyes were progressively increased in successive irradiations from 34.5 to 70.1 C., it was found that while temperatures of 45.6 C. and below produced no observable damage, temperatures of 66.2 C. and above resulted in lenticular opacities. Seven measurements were made in this series, the results of which may be seen in table I. These eyes were exposed at distances of 1 to 5 cm. for three minutes each.

TABLE I. — *Temperatures and Lenticular Changes Induced in Excised Eyes of Dogs and Rabbits Immediately After Microwave Irradiation of 100 Watts at 1 to 5 Cm. Distances for Three Minutes.*

No.	Temperature °C.	Lens
1	34.5
2	43.6
3	45.0
4	45.3
5	45.6
6	66.2	Opacity
7	70.1	Opacity

The lenticular opacities produced by irradiation under these conditions were located at the posterior pole of the lens and resembled cataracts produced by infra-red irradiation.

Eyes Intact Post Mortem; Rabbits. — In this series, lenticular changes were produced and the minimum temperatures necessary for their formation

6. Tuttle, W. W., and Janney, C. D.: The Construction, Calibration and Use of Thermocouples for Measuring Body Temperatures, Arch. Phys. Med. 29:416, 1948.

were more clearly defined, the same conditions of exposure being employed as for excised eyes—i. e., 1 to 5 centimeters distance for three minutes. Another group was added which was irradiated for fifteen minutes in order to obtain a slightly higher range of temperatures. The results of the irradiations of these two groups of animals are shown in table 2.

TABLE 2. — *Temperatures and Lenticular Changes Induced in Intact Eyes of Rabbits Post-mortem Immediately After Microwave Irradiation of 100 Watts at 1 to 5 Cm. Distances.*

No.	Time, Minutes	T° C.	Lens
1	15	50.0
2	3	53.5
3	3	54.8	Opacity
4	15	55.3
5	15	59.3	Opacity
6	3	60.0	Opacity
7	15	60.2	Opacity
8	15	61.8	Opacity
9	3	63.9	Opacity
10	15	67.5	Opacity

It may be seen that in the ascending scale of induced temperatures the results were negative to 54.8 C., a point at which traces of lenticular opacity were observed. At temperatures recorded above this, distinct cataractous opacifications were observed in all eyes except 1 which was increased to 55.3 C. In this eye, no lenticular changes were evident.

Upon the assumption that opacities were produced in the eye at induced temperatures of approximately 55 C., the next endeavor was an attempt to reproduce this condition in the eyes of living animals.

Eyes Intact in Vivo; Rabbits. — Using anesthetized albino rabbits, we made seven temperature measurements of the cornea and six of the vitreous at the posterior pole of the lens when irradiated at a distance of 5 cm. Temperatures were recorded at one minute intervals, during irradiation. The results are shown in chart 1. It was found that the average temperature at the posterior pole of the lens was increased to 55.1 C. in fifteen minutes, whereas the average temperature of the cornea at that time was 49.4 C. However, it was of some interest to observe that no opacities of the lens were present under these conditions.

Studies were continued further on 4 animals which were irradiated for seventeen to twenty minutes at a distance of 5 cm. Immediate examination with a hand slit lamp revealed opacities in the lens in all cases.

Upon a basis of this information, 3 animals were irradiated for seventeen minutes and 6 for fifteen minutes at a distance of 5 cm. without temperature measurements. Examined daily, in three to nine days in all the former and 5 of the latter lenticular opacities had developed. Since it was disclosed by these observations that cataractous changes could be developed many days following exposure and by irradiations of a smaller magnitude than those which produced an immediate opacity, further investigations were made with multiple exposures of yet smaller magnitudes on alternate days.

Six animals were given three exposures, each of twelve minutes' duration, at a distance of 5 cm., conditions which, judging from previous experiments, increased the temperature at the posterior pole of the lens to 53 C. In 3 of these animals opacities developed in two to ten days. A fourth revealed an opacity in forty-two days.

Four animals were irradiated for ten minutes' duration at 5 cm., raising the posterior lenticular temperature to an estimated 52 C., the number of

exposures in each case being three, four, six and seven. Under these conditions, 3 of the 4 animals showed lens changes in fifteen days. However, when 3 animals were given six exposures of three minutes each at 5 cm., previously shown to cause a 47.1 C. temperature at the posterior pole, no opacity was present upon observation at the end of four months.

Another series of animals was studied under conditions wherein the temperature of the cornea was raised rapidly and maintained for ten minutes. Six albino rabbits were employed in the first group, in which the temperature of the cornea was increased to 46 C. in an average time of three minutes and maintained at that temperature for ten minutes longer. In 4 of the 6 cataracts developed in six to twenty-four days. However, when the corneal temperatures of 5 animals were increased to 40 C. in an average time of one minute and maintained at that temperature for ten minutes longer, no opacity of the cornea or lens was apparent after thirty days.

A summary of these findings may be seen in table 3. In all cases the opacities were permanent. There was other occasional damage to the eyes, such as retinal hemorrhage and bleeding into the vitreous.

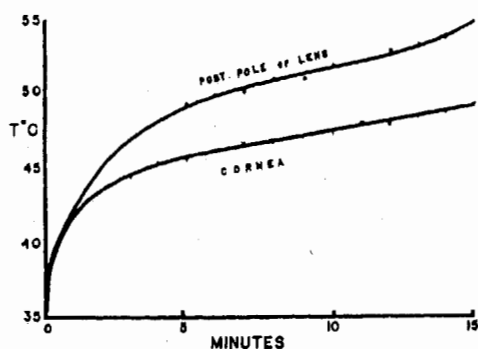


Chart 1. — In vivo corneal and lenticular temperatures of rabbit eyes irradiated with 100 watts of 12.25 cm. microwaves at 5 cm.

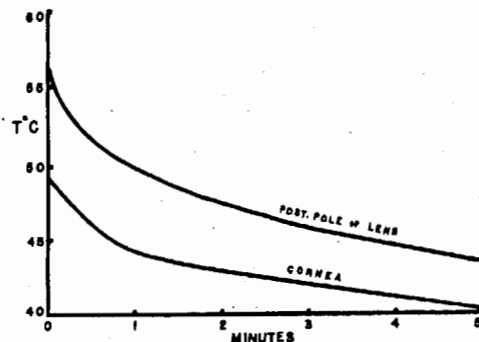


Chart 2. — In vivo corneal and lenticular temperature decay in rabbit eyes following irradiation with 100 watts of 12.25 cm. microwaves at 5 cm.

TABLE 3. — Summary of Results of Microwave Irradiations of Rabbit Eyes in Vivo at 5 Cm. Distance for Exposures of 3 to 20 Minutes.

Group	Number of Exposures	Min. of Each Exposure	Number in Group	Number With Cataract	Per Cent With Cataract
100 watt exposure					
1	1	17-20	4	4	100
2	1	17	3	3	100
3	1	15	6	5	83.3
4	3	12	6	4	66.7
5	3	10	4	3	75
	4				
	6				
	7				
6	6	3	3	0	0
Corneal temperature maintained at 46 C.					
7	3	10	6	4	66.7
Corneal temperature maintained at 40 C.					
8	3	10	5	0	0

In order to ascertain any discrepancies between temperature measurements taken continuously in the field and those taken after irradiation, temperature decay gradients following irradiation were plotted. Chart 2 represents the average temperature decay of the cornea and vitreous at the posterior pole of the lens over a five minute period following irradiation. It may be seen that there is a marked temperature drop during the first minute.

Of the 54 eyes which were irradiated under the various experimental conditions described, 32 were found to contain lenticular opacities. These opacities varied from small posterior polar masses to almost complete opacifications of the lenses completely obscuring the retina.

Comment

Since other workers have shown that the microwave generator serves an adequate purpose in medical therapy by inducing temperature increases in selected areas of the body, the findings in this report should not in any way discourage its employment in those areas as a thermogenic device. However, it is believed that precaution should be taken in the future with regard to irradiations in the region of the orbit. Although the conditions described in this report included irradiations of a greater magnitude than those routinely employed in therapy, it is noteworthy that the observations were carried out in all cases for a duration of less than twenty minutes.

These experiments suggest that precautionary measures may be of value to workers and patients frequently exposed to the radiations of microwave generators. It has been found by tests with microammeters that fine mesh copper screen wire shields worn over the eyes effectively diminish 100 watt microwave irradiations.

The findings herein described may prove to be of benefit to ophthalmologic research workers desiring an effective method for producing experimental cataract.

Summary

1. A direct single exposure of rabbit eyes to 12.25 cm. microwaves at 5 cm. distance for fifteen minutes with 100 watts power output resulted in cataractous lenticular opacities after a delay of three to nine days.
2. Under the conditions just stated for single exposures, the average temperature of the vitreous at the posterior pole of the lens was found to be 55.1 C. while that of the cornea was found to be 49.4 C.
3. A series of repeated exposures of a smaller magnitude resulted in cataractous lenticular opacities after a delay of two to forty-two days.
4. Four rabbits irradiated for seventeen to twenty minutes at 5 cm distance revealed cataract formations immediately after the irradiations.
5. The practical applications of these microwaves are discussed. Until further data are accumulated, precaution should be observed in the use of microwaves in the region of the face and orbit.

