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THE EFFECTS OF MICROWAVE DIATHERMY ON THE EYE OF THE RABBIT*

LOUIS DAILY, JR., M.D., KHALIL G. WAKIM, M.D., J. F. HERRICK, PH.D., EDITH M. PARKHILL, M.D., AND WILLIAM L. BENEDICT, M.D.
Rochester, Minnesota

In a previous publication[1] we have reported the results of a detailed study of the effects of microwave diathermy on the eye of the dog. The present paper describes a similar study in which the experimental animal is the rabbit. We wished to compare the temperatures as well as the clinical and pathologic changes which are produced by microwave diathermy in the eye of the rabbit with those we had observed in the eye of the dog. The rabbit is a particularly suitable animal for this study because certain experiments can be made without the complicating factor of anesthesia.

The same equipment as that used in our previous study[1] on the dog was employed in these investigations. Different distances of the microwave director from the eye surface and various durations of exposure to microwaves at an output of the generator of 94 watts were used with the hope of establishing a dose of microwaves which would not damage the eye. Furthermore, ophthalmoscopic studies were made on the eyes before and after exposure to microwaves; after enucleation, dissection or section and microscopic examination of some of the eyes were made in order to note the pathologic changes produced in the eye and to correlate our observations with distances, durations, and number of exposures causing these changes.

REVIEW OF LITERATURE

The literature on the effects of longwave and shortwave diathermy on the eye has been reviewed in a preceding publication,[1] and the review will not be repeated here. In our previous study we reported the production of anterior cortical cataracts in the eyes of dogs by repeated exposure to microwaves. Exposures were made once daily for 10 days, using an output of 94 watts from the microwave generator, at a distance of two inches (about 5.1 cm.) from the eye to the "C" director, for a duration of 30 minutes.

The anterior cortical cataracts which were produced by such exposures increased in size and density for several weeks, and then regressed in size and density for several weeks until they had almost disappeared. At this time posterior cortical opacities appeared and persisted thereafter. In eyes of other dogs, exposure to microwaves caused severe injury to other ocular structures.

METHODS

As in the previously reported study on dogs, the microwave generator used in this study on rabbits was an experimental model of the microtherm containing an air-cooled multicavity magnetron tube which generates microwaves at a frequency of 2,450 megacycles per second, corresponding to a wavelength of about 12 cm. The energy was transported from the generator to the director through a coaxial cable. Director "C," the corner-reflector type, was used exclusively in this study on the eye because the surface heat pattern of this director is confined to a relatively small oval area with maximal heating in the center of the pattern.

The temperatures were recorded galvanometrically in the eyes of rabbits by means of thermistors mounted in narrow-gauge polyethylene tubing. The deflections of the galvanometer were either read directly from the scale on a screen or recorded continu-

* From the Section of Ophthalmology, the Section of Physiology, the Division of Surgical Pathology, Mayo Clinic, and the Division of Experimental Medicine, Mayo Foundation. Abridgment of a portion of the thesis submitted by Dr. Daily to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Ophthalmology.

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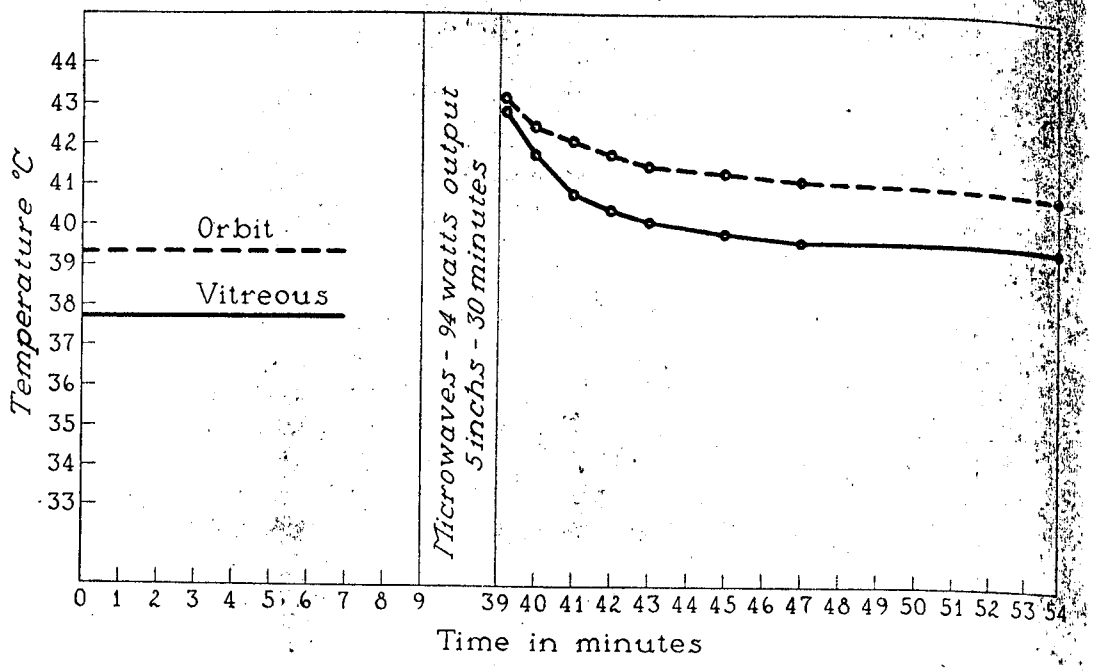


Fig. 1 (Daily, et al.). Temperature curves of deep orbital tissues and vitreous of an eye of an anesthetized albino rabbit before and after exposure to microwaves.

ously on a moving photographic film throughout the experiment.

In one series of experiments on 79 animals, the temperatures of the vitreous and of the deep orbital tissues were recorded before and after exposure of the eye to microwaves. To insure uniformity, the following procedure was carried out in each experiment.

The rabbit was anesthetized with diallylbarbituric acid, given intravenously. More anesthetic was administered when needed. To stabilize the eye without causing disturbance to the pattern of the electromagnetic field, nonmetallic supports were used to immobilize the head of the animal. The palpebral fissure of the rabbit remained open and the eyeball remained immobile during anesthesia.

After exposure of the sclera by excision and reflection of the conjunctiva from the upper temporal corneal limbus, a small scleral incision was made, through which the thermistor was introduced into the vitreous. A thermistor was inserted into the orbit through the conjunctiva near the inner canthus.

The thermistors were left in place in the rabbit during exposure to microwaves. The director was aimed at the cornea and was accurately spaced from the corneal surface. The distance from the cornea to the center of a plane joining the most anterior metal edges of the director was measured. The microwave generator was then turned on, and the output was kept constant by manipulating the variac as needed.

It was possible to record the temperatures accurately 15 seconds after discontinuation of the heating. The temperatures were continuously recorded for about one-half hour after the microwaves had been turned off.

In order to determine the optimal dose for production of safe elevations of temperature in the eye without damage to the ocular structures, a number of experiments were performed using seven procedures for exposing the eye of the rabbit to microwaves with different distances of the cornea from the director and different durations of exposures.

these various factors are listed in Table 1. Experiments were performed using albino and pigmented rabbits.

Results

Effects of Microwave Diathermy on the Temperature of the Vitreous and Orbit

In every group of experiments except one in this study the actual temperatures of the vitreous after exposure of the eye to microwaves were consistently higher than those of the deep orbital tissues. In the one exception mentioned, after the eyes of five albino rabbits had been exposed to microwaves at a distance of five inches (about 12.7 cm.) from the corner reflector with an output of 94 watts from the microwave generator for a duration of 30 minutes, the average temperature of the orbital tissues exceeded that of the vitreous (fig. 1). In every instance, the rise in temperature of the vitreous exceeded the rise in temperature of the deep orbital tissues (fig. 2).

A comparative study was made of the rises in temperatures in the eyes of albino and pigmented rabbits followed exposure to microwaves under identical conditions. The purpose of this comparative study was to determine whether the presence of pigmentation affects the degree of rise in temperature produced by microwaves in the eye.

In every experiment in this study the eyes were exposed to microwaves with an output of the microwave generator of 94 watts. In these experiments different eyes were exposed to microwaves at distances of 2, 3, 4, and 5 inches (about 5.1, 7.6, 10.2, and 12.7 cm.) from director C, and for durations of 10, 20, and 30 minutes, respectively. In order to determine average rises in temperature of eyes after exposure to microwaves, in each group of experiments at least five eyes were exposed to microwaves under identical conditions.

To avoid repetition of data (available in Table 1) on the temperatures produced in the vitreous and deep orbital tissues of the eyes of albino and pigmented rabbits after exposure to microwaves according to the specifications given for the seven different experimental procedures, only the average rises in temperature are presented in the text. Fifteen seconds after exposure to microwaves the average rises in temperature of the vitreous humor ranged from 3.7°C. to 14.6°C. and those of the deep orbital tissues from 1.6°C. to 6.3°C. (Table 1).

An interesting observation is the rate of

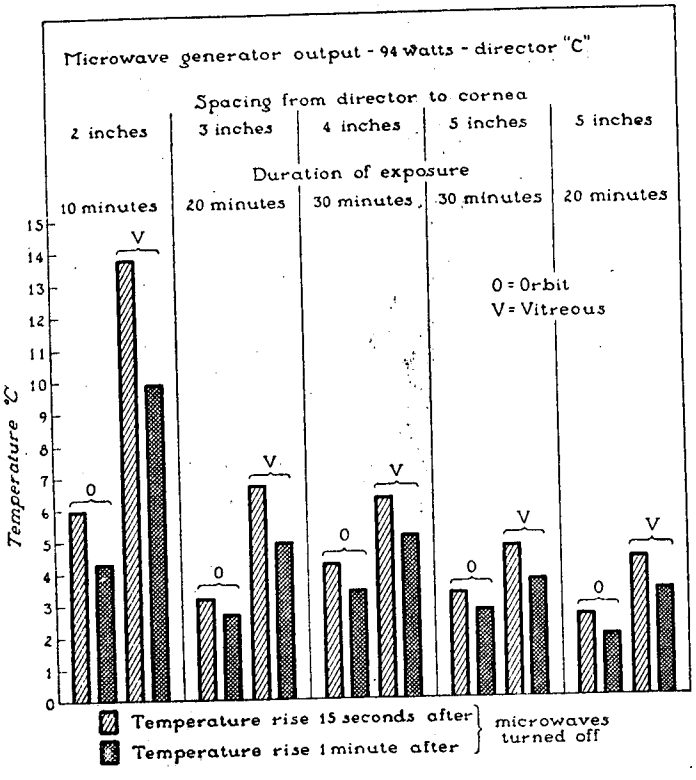


Fig. 2 (Daily, et al.). Temperature rises in deep orbital tissues and vitreous 15 seconds and one minute after exposure of eyes of rabbits (albino and pigmented combined) to microwaves. The rises of temperature represent averages from the number of experiments listed in Table 1.

TABLE 1

AVERAGE TEMPERATURES IN THE EYES OF ANESTHETIZED RABBITS BEFORE AND AFTER EXPOSURE TO MICROWAVES (OUTPUT 94 WATTS)

Group of Experiments		Number of Experiments	Color* of Rabbit	Distance of Director (inches)	Duration of Exposure (minutes)	Average Temperature, Degrees C.									
						Orbital Tissues					Vitreous				
						Before Exposure	15 Seconds After Exposure	Difference	1 Minute After Exposure	Difference	Before Exposure	15 Seconds After Exposure	Difference	1 Minute After Exposure	Difference
I	a	6	A	2	10	39.0	44.6	5.6	42.8	3.8	38.1	52.7	14.6	48.0	9.9
	b	6	P	2	10	38.9	45.2	6.3	43.7	4.8	37.9	51.0	13.1	47.8	9.9
II	a	6	A	3	10	39.1	41.1	2.0			38.5	43.4	4.9		
	b	5	P	3	10	38.7	42.2	3.5			36.8	44.0	7.2		
III	a	6	A	3	20	39.1	41.9	2.8	41.3	2.2	38.5	45.4	6.9	43.1	4.6
	b	5	P	3	20	38.7	42.7	4.0	41.9	3.2	38.4	44.9	6.5	43.6	5.2
IV	a	10	A	4	30	39.5	44.1	4.6	43.1	3.6	39.0	45.2	6.2	44.2	5.2
	b	5	P	4	30	39.6	43.5	3.9	42.8	3.2	39.4	45.8	6.4	44.5	5.1
V	a	5	A	5	10	39.2	40.8	1.6			38.5	42.2	3.7		
	b	5	P	5	10	39.2	41.2	2.0			39.1	42.8	3.7		
VI	a	5	A	5	20	39.2	41.4	2.2	41.0	1.8	38.5	43.2	4.7	41.7	3.2
	b	5	P	5	20	39.3	42.2	2.9	41.4	2.1	39.1	43.1	4.0	42.6	3.5
VII	a	5	A	5	30	39.5	43.0	3.5	42.6	3.1	38.1	42.8	4.7	41.6	3.5
	b	5	P	5	30	39.2	42.2	3.0	41.6	2.4	38.0	43.0	5.0	41.9	3.9

* A—Albino.
P—Pigmented.

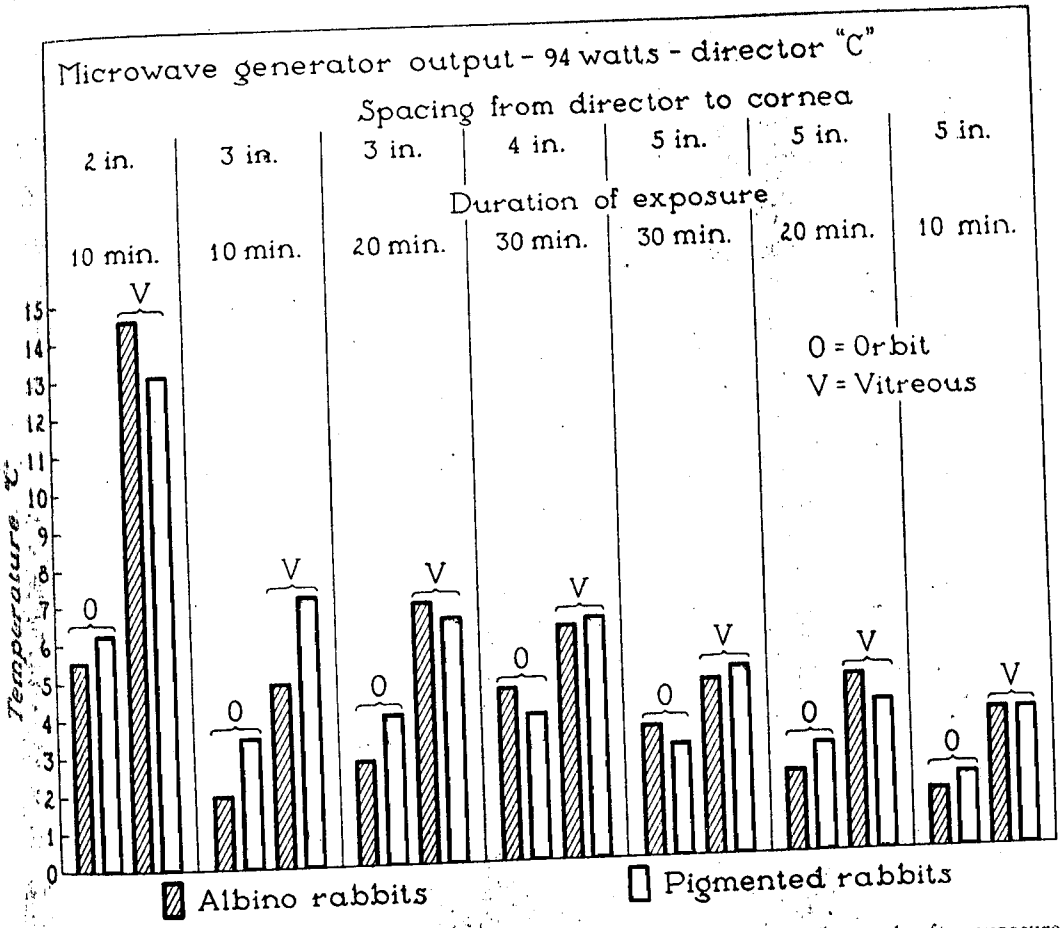


Fig. 3 (Daily, et al.). Temperature rises in deep orbital tissues and in vitreous 15 seconds after exposure of eyes of albino and pigmented rabbits to microwaves. The rises of temperature represent averages from the number of experiments listed in Table 1.

cooling of the eye after exposure to microwaves. As in the dogs,[1] so in many of the eyes of the rabbits the temperatures after exposure to microwaves did not return to control values but formed a new base line above the original level (fig. 1). This might be explained by the observation that in these animals there was a general rise in the temperature of the body after exposure to microwaves.

As in the previous study on dogs, in all the experiments a plateauing of the cooling curve was practically complete within 15 minutes after discontinuation of heating, and much sooner in the experiments in which there was relatively little rise in temperature following exposure to microwaves (fig. 1).

As in the previous study, the rapid rate of cooling of the vitreous was striking since this body is entirely avascular. Evidently most of the heat produced in this structure as a result of exposure to microwaves was carried away by the blood circulating in the vascular tunics adjacent to it.

No significant difference was found in the temperatures of eyes of albino and of pigmented rabbits following exposure to microwaves under identical conditions (fig. 3).

However, a significantly higher rise in the temperature of eyes of rabbits in this study than in eyes of dogs in the previous study occurred in every experiment in which the eyes of the animals were exposed to microwaves under identical conditions (fig. 4).

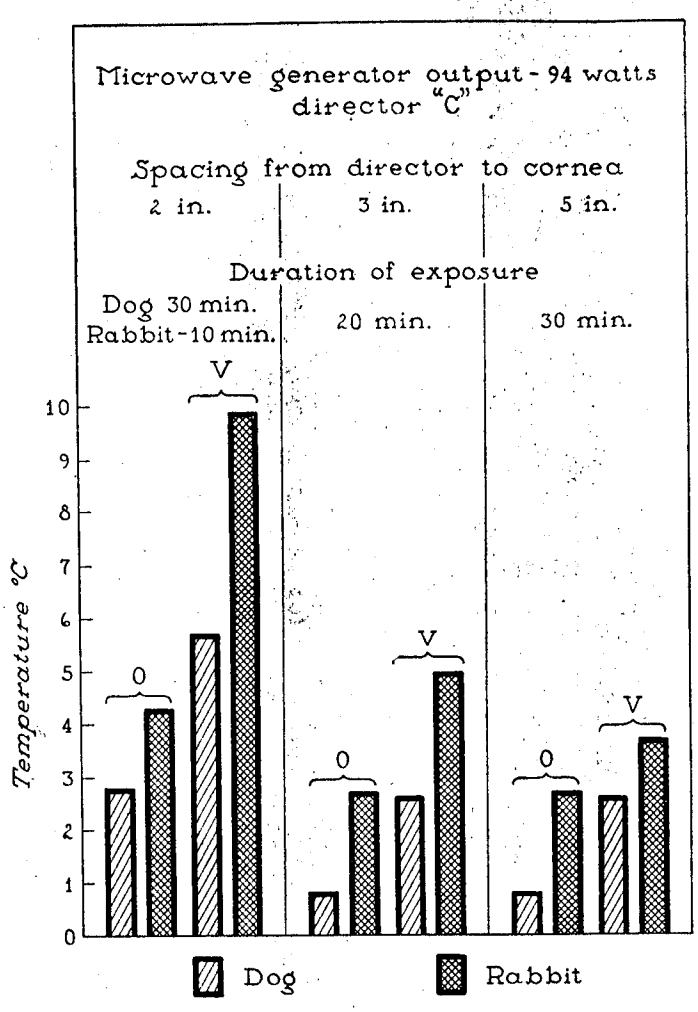


Fig. 4 (Daily, et al.). Temperature rises in deep orbital tissues and vitreous one minute after exposure of eyes of dogs and rabbits (albino and pigmented combined) to microwaves.

In this series of experiments, care was taken that eyes exposed to microwaves were not touched.

Five procedures for exposure of the eyes of rabbits to microwaves were used with different distances of the cornea from the director and different durations of exposure. These various factors are listed in Table 2.

Observations were made on the effect of the microwaves on the rabbit during and immediately after exposure of the eyes. Systemic, as well as ocular, effects of exposure were noted. Systemic effects which appeared during the exposure of the rabbit to microwaves included an increase in the respiratory rate, salivation, and, if the exposures were of sufficient intensity and duration, an increase in the rectal temperature.

In one rabbit, one exposure of the eye to microwaves at a distance of three inches (about 7.6 cm.) from the cornea to the director, with an output of 94 watts of the microwave generator for a duration of 25 minutes, terminated in a convulsive seizure and death of the animal. The rectal temperature of this animal immediately before death was 47°C.

In addition to these systemic effects, there was a marked tendency to vesiculation of the lower part of the ear on the side of the exposed eye. In some experiments measurement of the temperature of the ear indicated

Clinical and Pathologic Changes in the Eye after Microwave Diathermy

Another series of experiments was performed on six rabbits anesthetized as in the previous series and on 28 unanesthetized rabbits. The right eyes were exposed to microwaves at specific output, fixed distance, and duration. The left eyes were used for controls. No records of temperature were made in this series. However, the eyes were examined clinically, including examinations with the aid of the hand slitlamp and ophthalmoscopic examinations of the media and fundi, before and after each exposure to microwaves. The eyes of a number of the rabbits were dissected or sectioned and studied histologically.

TABLE 2

EFFECTS OF EXPOSURE OF EYES OF UNANESTHETIZED RABBITS TO MICROWAVES (OUTPUT 94 WATTS)

Group of Experiments	Number of Experiments	Color* of Rabbit	Distance of Director (inches)	Duration of Exposure (minutes)	Number of Exposures	Frequency of Exposures	Number of Eyes with Cataract	Days After Last Exposure Until Cataract Appeared	Remarks
I a	2	A	2	10	2	Once every 20 days	2	Rabbit 1: 0 Rabbit 2: 3	Both eyes burned, one severely
I b	2	P	2	10	6	Once every other day	2	Rabbit 1: 2 Rabbit 2: 7	Relatively dense opacities in lenses
II a	3	A	3	10	10	Once daily	1	13	Moderately large opacities
II b	3	P	3	10	10	Once daily	0		
III a	3	A	3	20	10	Once daily	2	Rabbit 1: 3 Rabbit 2: 14	Very small opacity in one lens, large in other
III b	3	P	3	20	10	Once daily	0		
IV a	3	A	4	30	10	Once daily	0		
IV b	3	P	4	30	10	Once daily	1	8	Relatively small opacity in lens
V a	3	A	5	30	10	Once daily	0		
V b	3	P	5	30	10	Once daily	0		

*A—Albino.
P—Pigmented.

a greater tendency for a rise in temperature of the ear than of the vitreous. In most of the experiments it was possible to prevent burning of the ear by covering it with cold, wet gauze during the exposure to microwaves.

Systemic effects were more pronounced when the distance of the director to the cornea was two inches (about 5.1 cm.) than at greater distances, but they were also marked when this distance was three inches (about 7.6 cm.). The shorter the distance, the sooner did systemic effects appear after the start of the exposure.

When the distance from the director to the cornea was two inches (about 5.1 cm.), the average duration of exposure until systemic effects appeared was about three minutes. When this distance was increased to three inches (about 7.6 cm.), the interval of time increased to about five minutes. Even when distances of four and five inches (about 10.2 and 12.7 cm.) were used, systemic effects were observed after intervals of exposure varying from 10 to 25 minutes.

Immediate effects of microwaves on the eyes and ocular adnexa varied with the method of exposure and possibly with the size of the rabbit.

Effects on the eye and ocular adnexa which usually appeared during the exposure of the rabbit to microwaves included blepharospasm, lacrimation, enophthalmos, miosis, and hyperemia of the conjunctiva. Blepharospasm appeared to be more marked in albino than in pigmented rabbits.

When the distance of the director from the eye was two inches (about 5.1 cm.), in some cases hyperemia of the iris appeared. In a few cases in which severe damage to the eyelids as well as to the eye resulted from exposure to microwaves, mydriasis appeared

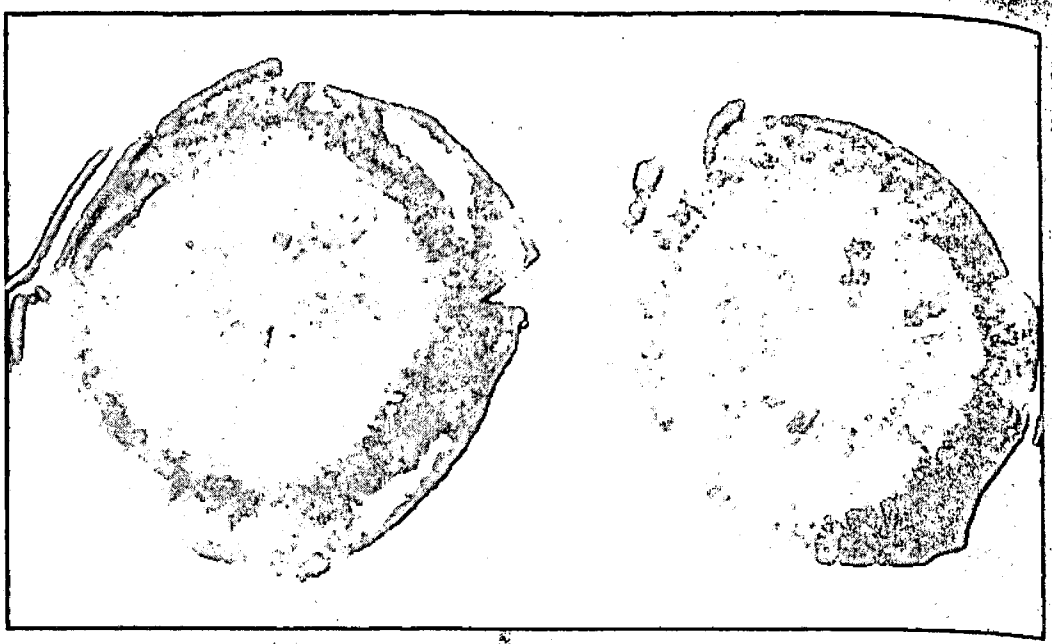


Fig. 5 (Daily, et al.). Photograph of the posterior surface of the iris and ciliary region of the eyes of an albino rabbit immediately after exposure to microwaves. Note the hemorrhage and congestion in the exposed eye (left).

during exposure to microwaves and persisted thereafter.

In eyes which were enucleated immediately after exposures to microwaves which produced severe damage to other ocular structures—namely, clouding of the cornea and hemorrhages into the iris and ciliary body (fig. 5)—dissection often revealed a diffuse, subcapsular clouding of the lens. If such eyes were not enucleated, mature cataracts developed rapidly in them.

Later effects on the eyes of rabbits following exposure to microwaves included changes in the lens as well as changes in the other parts of the eye. When the lens and other ocular structures were severely damaged after exposure to microwaves, the lens rapidly became opaque.

When clouding of the cornea and signs of severe inflammation of the iris and ciliary body were present immediately after exposure, severe iritis was usually followed by signs of permanent damage such as atrophy and increased vascularization of the iris. If secondary infection resulted from perforation of a corneal ulcer which followed exposure of the eye to microwaves, panophthalmia developed. Of more than 50 eyes of rabbits which were exposed to microwaves such severe damage occurred in only three.

In some eyes in which no obvious sign of gross injury to the lens or other ocular structures followed exposure to microwaves, a circumscribed posterior cortical opacity in the lens appeared only after an interval which varied from several days to several weeks.

Certain experiments were performed to determine the incidence of cataract produced in the eyes of unanesthetized rabbits after repeated exposure to microwaves with an output of 94 watts for various durations of exposure and at four different distances of the eye from the director. In each group of these experiments but one, equal numbers of albino and pigmented rabbits were exposed to microwaves under identical conditions.

This comparative study was done in order to determine whether the presence of pigmentation influences the changes produced in

the eyes of rabbits by microwaves. The various factors used in these experiments are listed in Table 2 and the findings were as follows:

Group I-*a*. One eye of each of two albino rabbits was exposed to microwaves twice, with an interval of 20 days, at a distance of two inches (about 5.1 cm.) for 10 minutes. Cataract developed in the exposed eyes.

Both of the eyes appeared to be burned, one severely, after the second exposure. In the severely burned eye the cataract progressed rapidly to maturity. In the other eye after an interval of three days the cataract appeared in the equatorial region of the lens and spread into the anterior and posterior cortex. Large vacuoles were conspicuous in the opacity, which was not sharply circumscribed.

Group I-*b*. One eye of each of two pigmented rabbits was exposed to microwaves for a total of six times once every other day at a distance of two inches (about 5.1 cm.) for 10 minutes. Cataracts developed in the eyes two and seven days respectively after the last exposure to microwaves.

The ophthalmoscopic appearance of one of these opacities five weeks after the last exposure of the eye to microwaves is shown in Figure 6-*a*. The opacity was composed of an upper and a lower portion, which were separated centrally by the horizontal suture but were confluent laterally beyond the suture.

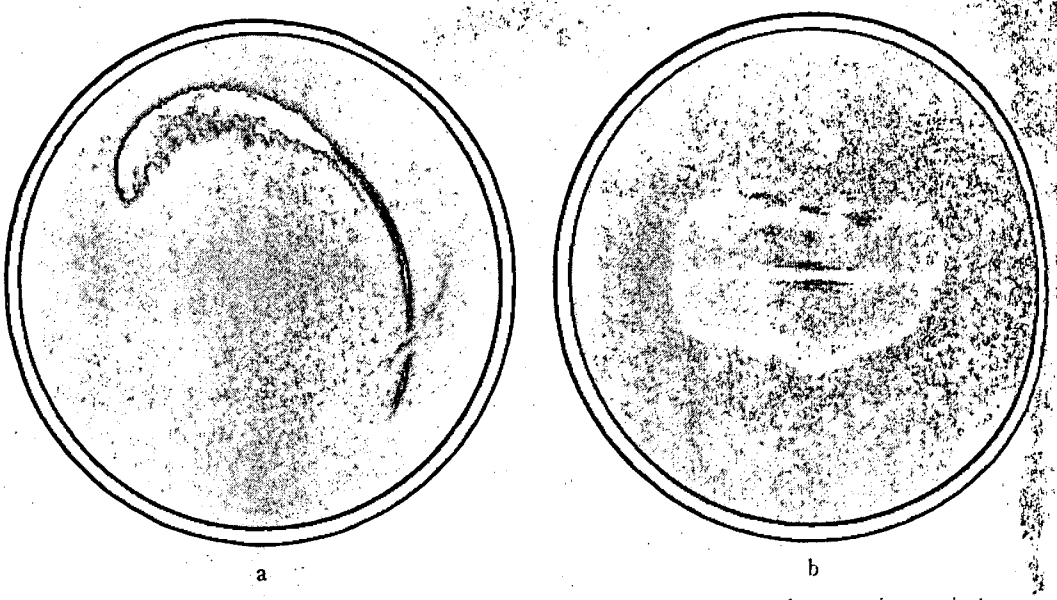
Five weeks later this opacity had changed in size, shape, and density so that its ophthalmoscopic appearance was that shown in Figure 6-*b*. The upper and lower portions of the opacity had separated further, and it seemed to be composed of small black granules. Eight weeks later the opacity seemed to have changed comparatively little.

The ophthalmoscopic appearance of the other opacity four weeks after exposure of the eye to microwaves is shown in Figure 7-*a*. The opacity was curved in shape and was located between the posterior pole and the equator of the lens.

Five weeks later the opacity had changed in density, size, shape, and position, so that its ophthalmoscopic appearance was that shown in Figure 7-*b*. It was now centrally located about the posterior horizontal suture. Thirteen weeks later the opacity seemed to

a b

Fig. 6 (Daily, et al.). (*a*) Drawing, as seen through the ophthalmoscope, of a posterior cortical cataract five weeks after exposure of the eye of a rabbit to microwaves. (*b*) Drawing of the same cataract five weeks later. Note the change in size and shape of the opacity.



a b

Fig. 7 (Daily, et al.). (*a*) Drawing, as seen through the ophthalmoscope, of a posterior cortical cataract four weeks after exposure of the eye of a rabbit to microwaves. (*b*) Drawing of the same cataract five weeks later. Note the change in shape and position of the opacity.

have undergone comparatively little change.

GROUP II-*a*. One eye of each of three albino rabbits was exposed to microwaves once daily for 10 days at a distance of three inches (about 7.6 cm.) for a duration of 10 minutes. Cataract developed in one of the eyes after an interval of 13 days following the last exposure to microwaves. This cataract increased in size and density for about one week. Two months later it had decreased in size and density. After another month it seemed to have undergone comparatively little further change.

GROUP II-*b*. One eye of each of three pigmented rabbits was exposed to microwaves once daily for 10 days at a distance of three inches (about 7.6 cm.) for a duration of 10 minutes. No cataract had developed in any of the exposed eyes after an interval of four months.

GROUP III-*a*. One eye of each of three albino rabbits was exposed to microwaves once daily for 10 days at a distance of three inches (about 7.6 cm.) for a duration of 20 minutes. Cataracts developed in two of the eyes after intervals of three and 14 days respectively following the last exposure to microwaves.

For four weeks after the last exposure to microwaves one of the cataracts continued to increase in size and density until its ophthalmoscopic appearance was that shown in Figure 8-*a*. The opacity was composed of a larger upper and a smaller lower portion separated by the posterior horizontal suture.

Five weeks later it had decreased in size and density until its ophthalmoscopic appearance was that shown in Figure 8-*b*. Seven weeks later the opacity had undergone comparatively little change.

At this time its appearance as seen by lateral illumination from a flashlight resembled that shown in Figure 9. It was white and was composed of radial opacities crowned peripherally by a row of annular opacities.

Periodic observation during a period of 12 weeks showed that the other opacity remained very small and faint whenever it was observed with the aid of either the hand slitlamp or the ophthalmoscope. With the aid of the hand slitlamp "water clefts" larger

were seen in the region of the posterior sutural suture in the normal lens of the were evident in the lens of this eye. seen through the ophthalmoscope, the appeared as a ring of small black dots surrounding the posterior pole of the lens.

Group III-*b*. One eye of each of three rabbits was exposed to microwaves once daily for 10 days at a distance of three inches (about 7.6 cm.) for a duration of 20 minutes. No cataract developed in any of the exposed eyes. One of the animals died of an infection one month after the last exposure. The two other rabbits were observed for a period of four months.

Group IV-*a*. One eye of each of three rabbits was exposed to microwaves daily for 10 days at a distance of four inches (about 10.2 cm.) for a duration of 30 minutes. No definite cataract developed in any of the exposed eyes.

One of the animals was killed 11 days after the last exposure to microwaves because of an infection. It was thought that a cataract might have begun to develop in the region of the posterior horizontal suture of the lens just before death; however, it was not possible to be certain of this. Otherwise no clinically visible signs of injury were present in the exposed eye.

Microscopic examination of this eye revealed dilatation of the vessels of the iris and congestion with hemorrhages into the ciliary processes. The other two rabbits were observed for one and four months respectively after the last exposures of the eyes to microwaves.

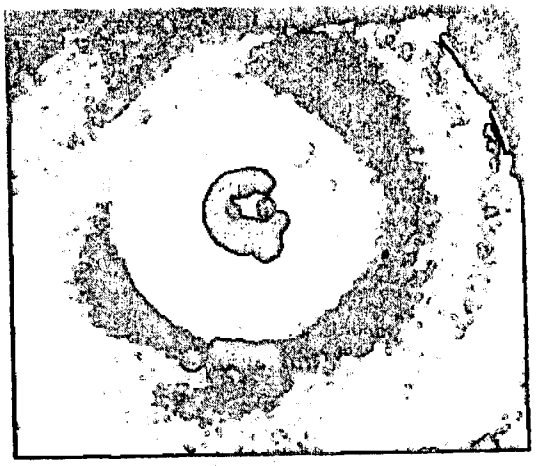


Fig. 9 (Daily, et. al.). Photograph showing a circumscribed posterior cortical cataract produced by exposure of the eye of a rabbit to microwaves.

a b

Fig. 8 (Daily, et al.). (*a*) Drawing, as seen through the ophthalmoscope, of a posterior cortical cataract six weeks after exposure of the eye of a rabbit to microwaves. (*b*) Drawing of the same cataract five weeks later. Note the regression of the opacity.

TABLE 3

EFFECTS OF EXPOSURE OF EYES OF ANESTHETIZED RABBITS TO MICROWAVES (OUTPUT 94 WATTS)

Number of Experiments	Color* of Rabbit	Distance of Director (inches)	Duration of Exposure (minutes)	Number of Exposures	Frequency of Exposures	Number of Eyes With Cataract	Days After Last Exposure until Cataract Appeared	Remarks
3	A	5	30	10	Once daily	2	Rabbit 1: 20 Rabbit 2: 23	Minimal changes in lenses
3	P	5	30	10	Once daily	0		

* A—Albino.
P—Pigmented.

GROUP IV-*b*. One eye of each of three pigmented rabbits was exposed to microwaves once daily for 10 days at a distance of four inches (about 10.2 cm.) for a duration of 30 minutes.

Cataract developed in one eye after an interval of eight days following the last exposure. The opacity was relatively small and lacking in density as compared with opacities produced by more severe methods of exposure of the eyes of rabbits to microwaves. The ophthalmoscopic appearance of the opacity was that of a cluster of small black dots just below the posterior horizontal suture of the lens. The opacity did not increase in size or density during a period of observation of one month.

The other two exposed eyes showed no change during a period of observation of about one and two months respectively after the last exposure of the eyes to microwaves.

GROUP V-*a*. One eye of each of three albino rabbits was exposed to microwaves once daily for 10 days at a distance of five inches (about 12.7 cm.) for a duration of 30 minutes. No cataract developed in any of the eyes during periods of observation of four weeks for one rabbit, and six weeks for the other two, after the last exposure of the eyes to microwaves.

GROUP V-*b*. One eye of each of three pigmented rabbits was exposed to microwaves once daily for 10 days at a distance of five inches (about 12.7 cm.) for a duration of 30 minutes. No cataract developed in any of the eyes during a period of observation of about eight weeks after the last exposure of the eye to microwaves.

STUDIES ON ANESTHETIZED RABBITS

In addition to the studies in which clinical observations were made of the eyes of rabbits after exposure to microwaves, a study was made of the eyes of anesthetized rabbits after exposure to microwaves.

This study of the effect of microwaves on the eyes of anesthetized rabbits was made in addition to the studies which were made on the unanesthetized rabbits because studies of changes in the temperatures after exposure of the eye to microwaves had been made only in anesthetized rabbits.

In the unanesthetized rabbits no cataracts had developed after exposure of the eye to microwaves daily for 10 days at a distance of five inches (about 12.7 cm.) for 30 minutes.

Temperatures had been determined in the eyes of anesthetized rabbits 15 seconds after exposure to microwaves at a distance of five inches (about 12.7 cm.) for a duration of 30 minutes. In 10 rabbits the average temperature of the vitreous immediately behind the lens was 42.9°C. with a range of 40° to 45°C.

The experiments in which the eyes of anesthetized rabbits were exposed to microwaves were as follows (Table 3):

One eye of each of three anesthetized albino and three anesthetized pigmented

rabbits was exposed to microwaves once daily for 10 days at a distance of five inches (about 12.7 cm.) for 30 minutes.

Cataracts were observed in the eyes of two albino rabbits after delayed intervals of 20 and 23 days respectively following the last exposure. The two cataracts were small and not dense.

Through the ophthalmoscope they appeared to be composed of small black dots located in the region of the posterior horizontal suture of the lens. Over a period of five weeks they seemed to change little in appearance. No cataracts had developed in the eyes of the pigmented rabbits after an interval of eight weeks following the last exposure to microwaves.

The fact that cataracts were produced in the eyes of anesthetized rabbits following exposure to microwaves under identical conditions to those which had not produced cataracts in the eyes of unanesthetized rabbits seemed to indicate that the temperature in the eyes of anesthetized rabbits was higher than in the eyes of the unanesthetized rabbits following exposure to microwaves under identical conditions.

Morphologic changes

In addition to studies on the temperature and the incidence of cataracts following exposure of the eyes of rabbits to microwaves under varying conditions of exposure, a careful study was made of the morphologic changes in the cataracts resulting from exposure to microwaves. Some of these changes have already been mentioned.

The following features were found to be common among the posterior cortical cataracts produced in the eyes of rabbits only after a delayed interval following exposure to microwaves.

The first change in the lens from the normal appearance that could be seen with the aid of the hand slitlamp was an enlargement and extension of the "water clefts." Unlike the human lens, these "water clefts" are normally present in the region of the conspicuous posterior horizontal suture that lies under the posterior capsule of the lens of the rabbit. In addition to the extension of the "water clefts," vacuoles often became visible in this region. The lens fibers, which were normally invisible, became opaque and resembled brown moss, since they seemed to form an irregular tangle with one another.

The earliest appearance of a cataract in the eyes of rabbits as seen with the ophthalmoscope was that of small black dots, sometimes arranged in an uneven line to form an ellipse or circle about the posterior horizontal suture.

The growth of the cataract varied in different lenses. In general, the greater the dosage, the larger was the opacity (Table 2).

Spread of the opacity was always in an equatorial direction. The opacity did not extend anteriorly into the nucleus of the lens; it was confined to the region of the lens under the posterior capsule. The opacity did not extend toward the equator for an equal distance in each meridian.

In some lenses the denser parts of the opacity during some phase of progression of the cataract were limited to a region between the posterior pole and the equator in one half of the lens (fig. 7-*a*). The opacity was often symmetrical in design.

Many of the opacities increased in size and density for about one month, and then diminished in density, and sometimes in size and shape, during the second month (figs. 6, 7, and 8). After the second month comparatively little change took place in the appearance of the cataract. One part of the lens might appear to contain the densest portion of the opacity at one time, only to be almost free of opacification at a later date (fig. 6).

Comment

If a certain range of dosage of microwaves which does not damage the eye can be found, microwave diathermy may provide a useful method for producing therapeutic elevations of temperature in the eye. The waves are focused by director "C" so that

most of the heat produced is localized to a small region in the tissues. This allows efficient heating of small organs such as the eye without undue heating of the surrounding structures.

On the other hand, this study demonstrates that microwaves can damage the eye if dosage is not carefully managed. Damage can result even from only one exposure. One or all of the ocular structures may become acutely inflamed. Moreover, repeated exposure over a period of days or weeks may cause injury if the distance, duration, and amount of microwave energy are not carefully controlled. The cataracts which developed in the eyes of rabbits, as in the eyes of dogs in the previous study, after repeated exposure to microwaves are a good example of such damage.

Why lens opacities were not accompanied by clinically visible extensive changes in the intraocular structures after repeated exposure of the eye to a high concentration of microwave energy is not clear. It is possible that the lens reaches a higher temperature than any of the other intraocular structures during exposure of the eye to microwaves.

We have shown in the previous study on dogs[1] that the aqueous and vitreous reach a higher temperature than the deep orbital tissues; presumably this is because they are avascular and must depend on the circulation in surrounding structures to dissipate the heat. The lens is an avascular body, surrounded mostly by avascular structures by means of which loss of heat is relatively inefficient. Therefore, a higher temperature might develop in the lens than in other intraocular structures because it is relatively isolated from circulating blood.

On the other hand, dissection and microscopic examination of some eyes of rabbits containing the circumscribed posterior cortical type of cataract which followed exposure to microwaves only after a delayed interval of time, demonstrated the presence of hemorrhagic infarcts in the ciliary processes.

Such examinations were not made of all eyes containing this type of cataract. Consequently, it is possible that this type of cataract may be a type of cataracta complicata which is formed secondarily. The site of primary injury in this case would be the ciliary processes, which might be damaged by the heating effect of the microwaves.

The possibility that this type of cataract is not produced directly by the heating effect of the microwaves on the lens per se would seem to be supported by data which we obtained in a study of the effect of microwaves on certain enzyme systems in the lens.[2] In this study, no loss of activity of the adenosintriphosphatase, the pyrophosphatase, or of the three peptidases was found in lenses containing this circumscribed posterior cortical type of cataract.[2]

The structure of the cataracts produced by exposure to microwaves is of interest. Both cataracts produced in the eyes of dogs[1] consisted of linear sutural opacities from which opaque feathery fibers of the lens radiated. Both of these cataracts first developed in the anterior cortex of the lens just beneath the capsule. One was a typical rosette cataract.

At a later date, posterior cortical opacities appeared in the lenses of the exposed eyes of both dogs. These cataracts resembled the early lens opacities which have been reported to occur after exposure of the eyes of pigmented rabbits to infrared radiations.[3]

Infrared cataract, which has been encountered as an occupational disease in glass blowers and puddlers, is typically a posterior polar opacity and involves the posterior subcapsular cortex or, less frequently, the nucleus of the lens.[3]

The circumscribed cataracts which followed exposure of the eyes of rabbits to microwaves only after a delayed interval of time were limited to the posterior cortex in the eyes of both albino and pigmented rabbits.

This is of interest in view of the inability of Vogt[4] to produce a cataract in this location in the lens of pigmented rabbits by exposure of the eyes to infrared radiation. He was able to produce a type of cataract closely

resembling the circumscribed posterior cortical type of cataract only in the eyes of albino rabbits, by exposure to infrared radiation. By exposure to infrared radiation he did produce a type of cataract in the eyes of pigmented rabbits which closely resembled the anterior cortical type of cataract produced in the eyes of dogs by exposure to microwaves.

Vogt[4] postulated that the reason for the difference in location of the cataracts produced in the eyes of albino as compared with pigmented rabbits by exposure to infrared radiation was the presence of the pigment in the iris of the pigmented rabbits. The pigment, he thought, absorbed the infrared radiation to a greater degree than nonpigmented ocular tissues.

He stated that the energy of the radiation was converted to heat in the iris, and the heat was conducted directly from the iris to the anterior part of the lens. Consequently, the anterior part of the lens was heated more than the posterior part, so that the cataract developed in the anterior cortex in the pigmented rabbits.

No ready explanation is at hand for the fact that the circumscribed type of cataract produced in the eyes of both albino and pigmented rabbits by exposure to microwaves was limited to the posterior cortex of the lens.

One possible factor which might aid in the explanation of this fact might be the failure of the pigment of the iris to absorb microwave radiation to a greater degree than nonpigmented ocular tissues. On the other hand, the two cataracts produced in the eyes of dogs[1] by exposure to microwaves both appeared in the anterior cortex of the lens.

No ready explanation based on anatomic or physiologic differences between the eyes of dogs and those of rabbits suggests itself for the difference between the locations of the cataracts produced in the eyes of these two species of animals by microwaves.

Reversible opacities of the lens are not in themselves remarkable, but the ability of the lens to recover from injury caused by repeated exposure to microwaves is worthy of comment. Why the anterior cortical opacification in the eyes of dogs, and to a lesser degree the posterior cortical opacification in the eyes of rabbits, should be reversible is not understood.

The rapid cooling of the vitreous after exposure to microwaves was of interest to us, in view of the avascularity of the vitreous.

It should be emphasized that the temperatures measured even 15 seconds after exposure of the eye to microwaves are not the maximal temperatures reached in the aqueous and vitreous during the exposure to microwaves. A glance at the slope of the cooling curves (fig. 1) during the first and second minutes after exposure to microwaves, or inspection of the differences between the rises of temperature of the orbit and vitreous 15 seconds and one minute after exposure to microwaves (fig. 2), indicates that the temperatures have undoubtedly been falling comparatively rapidly during the first minute after exposure.

The curves indicate that the greater the rise of temperature during heating, the more rapid is the fall after the heating is stopped. Consequently, any conclusions which may be drawn as to the safety of a stated dose and technique of application of microwaves to the eye are better judged by the absence of pathologic changes than by the magnitude of the rise in the recorded temperatures.

The difference between the rise in temperature in the eyes of dogs and in the eyes of rabbits following exposure to microwaves under the same conditions was significant (fig. 4). The fact that under each condition of exposure the temperature in the eyes of rabbits rose to a higher level than the temperature in the eyes of dogs may be explained, at least in part, in several ways.

One explanation for this fact would take into account the much larger size of the dog than of the rabbit. The smaller rabbit would be unable to dissipate the heat produced locally by the microwaves as effectively as the dog.

A second explanation would take into account the smaller size of the head of the rabbit compared to that of the dog. The microwaves directed toward the eye of the rabbit might elevate the temperature of the brain to a sufficient extent to influence the heat-regulating center; this possibility would be less likely in the case of the dog than in that of the rabbit.

The incidence of cataract that developed after exposure to microwaves of the eyes of albino rabbits as compared with pigmented rabbits was of interest. Of 17 albino rabbits whose eyes were exposed to microwaves, cataracts developed in seven; while of an equal number of eyes of pigmented rabbits that were exposed to microwaves under identical conditions, cataracts developed in only three (tables 2 and 3). Only when the exposure was made at a distance of four inches (about 10.2 cm.) for 30 minutes was the incidence of cataract greater in the pigmented rabbits than in the albino rabbits, and in this case the number of rabbits involved was too small for the difference in incidence to be statistically significant.

No satisfactory explanation is at hand for the greater number of cataracts that developed in the eyes of albino rabbits than in the eyes of pigmented rabbits after exposure to microwaves under identical conditions.

One possible explanation might be the production of higher temperatures in the eyes of albino rabbits than in the eyes of pigmented rabbits by exposure to microwaves under identical conditions. However, the studies of temperatures in the eyes of rabbits following exposure to microwaves demonstrated that there was no significant difference between the temperatures in the eyes of pigmented rabbits and in the eyes of albino rabbits 15 seconds after exposure to microwaves under identical conditions.

Summary

In order to determine the changes in temperatures of the orbital tissues and vitreous after exposure of eyes of rabbits to microwaves, and to determine the pathologic changes in the eyes resulting from exposure to microwaves, a study was made of the effects of various durations of exposure on intact as well as enucleated eyes at different distances and durations.

One series of experiments was performed on 79 rabbits anesthetized with diallylbarbituric acid, administered intravenously. Thermistors were introduced into the orbit and vitreous of the eyes of rabbits, and the temperatures were recorded before and after exposure to microwaves. The cooling curves were followed for about one-half hour after the microwaves had been turned off.

Of the 17 eyes of albino rabbits exposed to microwaves for durations of 10 to 30 minutes using 75-percent output (94 watts) with the director at distances of two to five inches (about 5.1 to 12.7 cm.), cataracts developed in seven eyes. Of 17 eyes of pigmented rabbits exposed to microwaves under the same conditions that were used in experiments on the eyes of albino rabbits, cataracts developed in only three eyes.

The cataracts which were produced in the eyes of rabbits by exposure to microwaves were of two types:

In one type the cataract was present immediately after exposure to microwaves, when it involved diffusely the region of the lens under the capsule. The cataract progressed rapidly until the entire lens became opaque. This type was seen only when grossly visible damage to other ocular structures was produced; namely, clouding of the cornea with congestion and hemorrhages into the iris and ciliary processes.

The second type of cataract was not associated with obvious gross clinical signs of injury, although dissection and microscopic examination of some eyes containing such cataracts had demonstrated the presence of hemorrhagic infarcts in the ciliary processes. This type of cataract did not appear immediately after exposure to microwaves, but became visible only after a period of time varying from several days to several weeks. It

as limited to the posterior cortex, but could e made to progress and involve the entire ens by repeated exposure of the eye to icrowaves.

Exposure, for a duration of 10 minutes, of he eye of a rabbit at a distance of two nches (about 5.1 cm.) from the corner reector with an output of 94 watts from the icrowave generator might produce either of he foregoing types of cataracts.

With the aid of the hand slitlamp the posterior cortical cataracts produced in the eyes of rabbits by exposure to microwaves were observed to begin by an enlargement and extension of the "water clefts" that are seen in the region of the posterior horizontal suture in the normal lens of the rabbit. Through the ophthalmoscope the first appearance of the cataract was that of a number of small black dots usually located in the region of the posterior horizontal suture.

Many of the larger opacities produced in the eyes of rabbits by exposure to microwaves progressed in size and density during the first month after becoming visible ophthalmoscopically. During the following month they regressed in size and density, and changed in shape and position. Thereafter the size, shape, position, and density of the cataracts appeared to change relatively little.

Mayo Clinic.

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HEREDITARY MICROCORNEA AND CATARACT IN FIVE GENERATIONS*

M. WALLACE FRIEDMAN,† M.D., AND EDWIN S. WRIGHT,‡ M.D.
North Hollywood, California

The pedigree presented herein offers an interesting study in the hereditary aspects of congenital cataract and microcornea. Authorities differ somewhat in their definition of congenital cataract.

Clapp[1] states: "It seems wise to consider as congenital cataract an opacity in the lens layer enough either to interfere with vision or to show some disturbance of the normal fundus reflex when viewed with the indirect ophthalmoscope after dilation of the pupil."

Mann[2] expresses the opinion: "Any opacity, whether total or so small that it can only be seen by focal illumination with the slitlamp, is technically a cataract."

The definition of microcornea is purely one of measurement. The normal corneal diameter is 12 mm. in its greatest chord (horizontal) and any value less than 10 mm. is considered to be microcornea.

MICROCORNEA

Information concerning microcornea is scanty. It is generally thought to be a component of either microphthalmus or anterior-

* From the Department of Ophthalmology, Los Angeles County Hospital.
† Senior resident in ophthalmology, College of Medical Evangelists Service, Los Angeles County Hospital.
‡ Assistant clinical professor of ophthalmology, College of Medical Evangelists.