THEORETICAL AND EXPERIMENTAL STUDIES OF MICROWAVE INDUCED CATARACTS IN RABBITS

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Abstract

Power deposition patterns, temperature distribution patterns, and cataractogenesis thresholds have been established in the eyes of rabbits exposed to localized near zone 2450 MHz radiation. There was good agreement between results obtained through theoretical and experimental approaches.

Summary

The results of previous microwave cataractogenesis research on test animals does not provide sufficient quantitative data to describe the relationship between various physical parameters and the biological changes in the eye. The results of animal research will not be useful in predicting safety guides for humans unless these relationships can be accurately established. The research reported here has been formulated to relate exposure field levels, eye and head geometry, absorbed power patterns, and induced temperature distributions, to the location and threshold of cataract formation.

The electromagnetic field patterns, both in and outside the eyes and head, were determined for rabbits exposed to a 2450 MHz diathermy "C" director. Five 8 month old albino rabbits (2 female, 3 male) averaging 3.6 Kg, were anesthetized with acepromazine and nembutal. While under general anesthesia, the animals were exposed to the 2450 MHz "C" director with the corneal surface 5 cm from the cross-over point of the feed. Absorbed power distributions were determined by measuring the short-term temperature rise in the tissues due to a brief exposure to high power radiation as described by Johnson and Guy [1]. The temperature changes were measured by inserting a thermocouple into a glass micropipette placed along the anterior-posterior axis of the eye at increasing depths. The thermocouple was inserted only after the radiation was off. The incident power density at the same position as the eye was measured with a Narda 8100 electromagnetic radiation monitor in the absence of the rabbit. The absorbed power distributions, in all cases, reached peak values in the vitreous body at about half-way between the lens and the retina with a mean of 0.92 mW/gm for each mW/cm^2 incident power (Fig. 1). In order to verify these measurements, tests were run under identical exposure conditions but with the thermocouple probe inserted vertically 3.5 mm behind the superior limbus. Exact correlation was found between the two measurement techniques.

The ocular dimensions of the fellow eye were measured as a guide in gauging the location of the thermocouple probe in the other eye, because passage of the probe into the lens prevented direct visualization of its tip. This was done by first enucleating and then freezing the fellow eye upon completion of the experiment. After complete solidification, the eye was bisected sagitally and anterior-posterior measurements were made of the corneal thickness, anterior chamber depth, lens, and the distance between posterior lens capsule and retina. Rectal temperature and pulse rate were monitored throughout the experiment and recorded before and after each exposure. The rabbits in general showed an average increase of rectal temperature of 0.97°C (Fig. 5) and an increase in pulse rate of approximately 30 percent.

A computer program was developed to predict temperatures at any point in the globe for variable ambient and orbital temperature conditions. These calculations were based on a spatially constant specific heat equal to that of a saline solution, a vitreous humor thermal conductivity of 5.94 mW/cm/°C as measured in beef eyes, and a lens thermal conductivity of 2.13 mW/cm/°C obtained by ratioing the electrical conductivities. These conductivities were checked by calculating the eye temperatures in a non-irradiated eye with an orbital temperature of 37.8°C as reported by Schwartz and Feller [2], and excellent agreement was obtained at all points along the pupillary axis. Calculations were then made for several exposure levels using the measured absorbed power distribution shown in Fig. 1. In all cases the maximum temperatures were localized in the retrolental area near the posterior surface of the lens. After a subthreshold dose of radiation of 100 mW/cm^2 for 60 minutes, the maximum temperature was 40.7°C, slightly greater than the assumed blood temperature of 39°C (Fig. 2). A radiation dose of 300 mW/cm^2 for 30 minutes indicated an inordinate rise to 46°C and a corneal temperature of 37.7°C (Fig. 3) when normal evaporation from the front surface of the eye was assumed. For a non-irradiated eye, the normal evaporative heat loss accounts for approximately 30 mW/cm^2, or 2/3 of the total heat transferred from the front surface of the eye to the ambient air. With rapid blinking and copious irrigation, this evaporative loss could easily rise to values of 200-300 mW/cm^2.

Calculations performed for 300 mW/cm^2 incident power and 5 times normal evaporative cooling rates show a maximum temperature of 44.9°C and a corneal temperature of 24.9°C (Fig. 4). A further reduction of the maximum temperature by increased evaporation from the surface of the eye is unlikely because the lens' low thermal conductivity is an effective barrier to heat flow and forces most of the heat loss to be by conduction to the orbit.

For comparison with the calculated values, the thermal response at the posterior surface of the lens was determined by measuring the retrolental temperature rise in an anesthetized rabbit during a 100 mW/cm^2 exposure for 60 minutes. The irradiation was interrupted every five minutes to measure the temperature. The time between turning off the radiation and inserting the thermocouple is indicated on Fig. 5 and the average interruption of radiation was 30 seconds. Rectal and room temperatures and humidity were monitored. An intravitreal temperature plateau was reached after a total of 25-30 minutes of irradiation, the maximum temperature recorded being 40.6°C (Fig. 5).

The predicted maximum in this area was 40.7°C (Fig. 2). There was a concomitant rise in rectal temperature. After irradiation, a rapid cooling in the vitreous occurred initially, which then reached a plateau about 1°C above the baseline. The rectal temperature similarly remained 1°C above the pre-irradiation level.

Williams, et al. [3] and Carpenter and his associates [4] [5], have reported time and power thresholds for cataractogenesis by 2450 MHz radiation; however, their results were in variance from each other (Fig. 6). This was not surprising since the results depended highly on the method and accuracy of the dosimetry. To reconcile the differences, a program aimed at establishing similar thresholds based on incident and absorbed powers, as well as induced intraocular temperatures, was initiated. Three adult rabbits were used for each exposure condition. Pre- and post-irradiation examinations of the fully dilated eyes were made with a slit-lamp and ophthalmoscope. The earliest lens damages, consisting of posterior cortical banding and small vacuoles in the region of the posterior suture line, made their appearance usually within the first week after exposure. These changes, seen only by slit-lamp examination, showed no progression at the lower levels of irradiation. At higher levels of exposure (300 mW/cm^2 for 40 minutes) the vacuoles increased in number and a distinct, well-circumscribed subcapsular opacity developed which was easily seen with an ophthalmoscope. A few of the animals developed opacities in the equatorial region as well.

The results of these preliminary exposures seem to fall slightly above the cataractogenesis curve of Carpenter (Fig. 6). They are also consistent with the predicted temperature rises given by numerical computations.

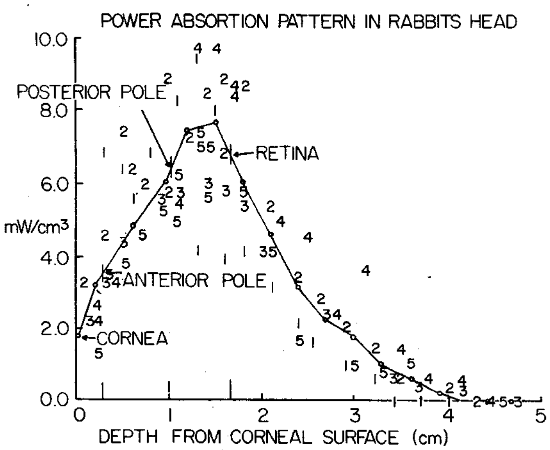

Fig. 1 Power absorption in rabbit's eye and head.

Scale for absorbed powers - 1 watt to applicator (8.42 mW/cm incident) *-mean of 5 rabbits.

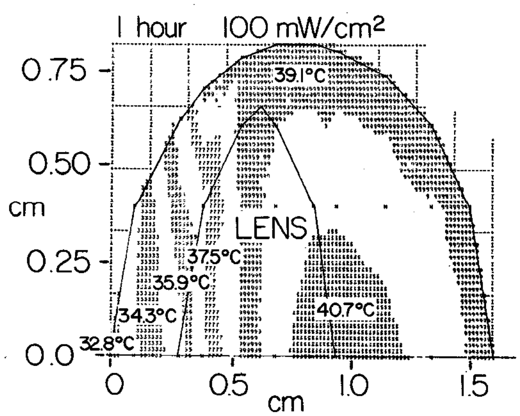

Fig. 2 Predicted intraocular temperature distributions of an eye exposed to 2450 MHz radiation.

References

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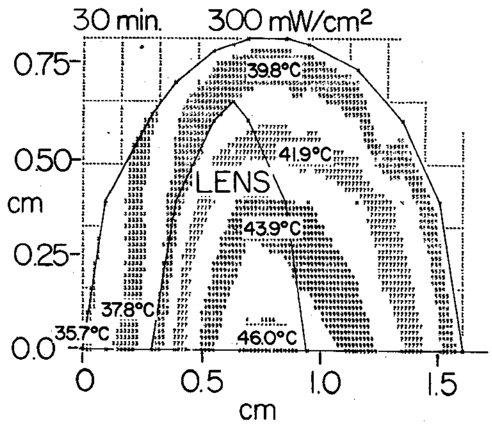

Fig. 3 Predicted intraocular temperature distributions of an eye exposed to 2450 MHz radiation.

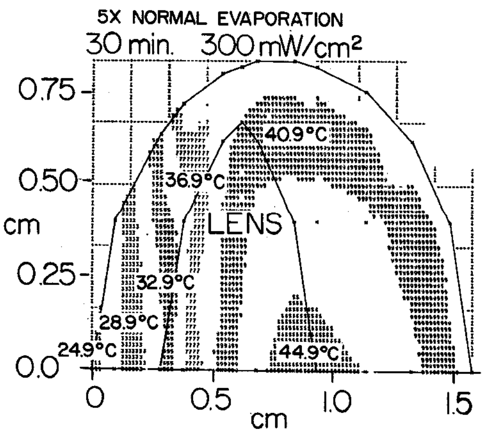

Fig. 4 Predicted intraocular temperature distributions of an eye exposed to 2450 MHz radiation.

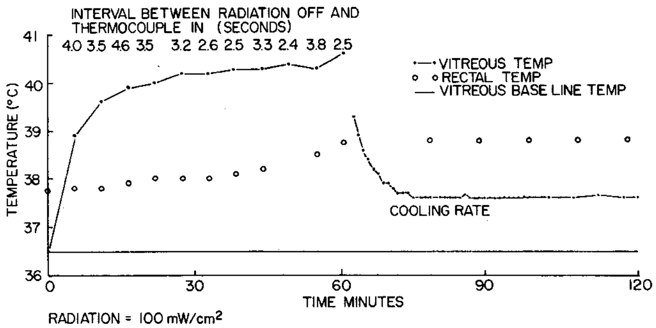

Fig. 5 Heating and cooling rates in the retrolental area.

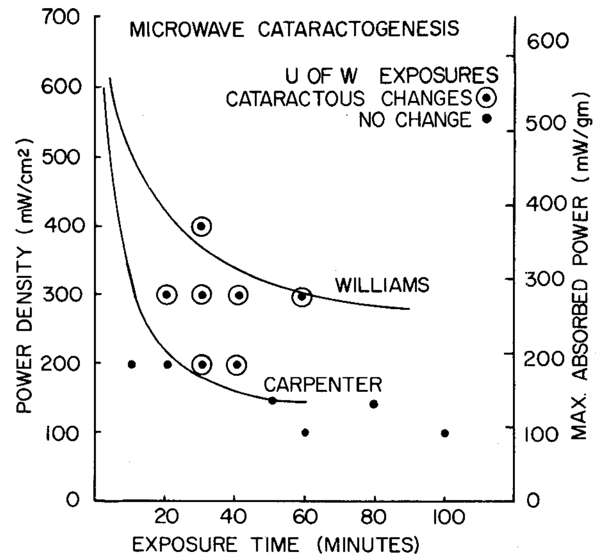

Fig. 6 Time and power thresholds for induction of cataractous changes by single dose irradiation at 2450 MHz.