REVERSIBLE IRRITATIVE EFFECT OF ACUTE 2.45GHZ MICROWAVE EXPOSURE ON RABBIT EYES - A PRELIMINARY EVALUATION

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ABSTRACT — We have attempted to determine if there is a hazardous effect of acute microwaves at 2.45GHz on the eye of a rabbit under lengthy exposure without anesthesia, the contralateral eye serving as a control. Unilateral eyes of 9 adult Japanese white rabbits (10 - 12 weeks of age) were irradiated by 2.45GHz continuous wave (CW) microwave for 160 min. to 240 min. under restraint without anesthesia. The specific absorption rate (SAR: phantom material) was 26.5 W/kg. The corneal surface temperature increment was 3.0°C for 15 min. on average. Miosis occurred in all rabbits within 15 min. Post-exposure ophthalmological signs, first detected as the effect of CW irradiation, included 1) miosis and pupillary congestion; 2) keratoconjunctivitis and corneal edema; 3) endothelial cell detachment and floating in aqueous humor; 4) fibrinogenesis in the anterior chamber; and 5) conjunctiva edema, which disappeared one week after exposure. There was no cataract formation. The acute microwave irradiation to the rabbit eye, causing the miosis and pupillary congestion in all irradiated eyes, was the first to be detected.

KEY WORDS: Microwave, Rabbit, Eyeball, Miosis, Pupillary congestion

INTRODUCTION

Because mobile and portable communication systems have been used in the vicinity of the human body, potentially hazardous effects of microwaves may arise among users and their neighbors. It was reported that portable communication systems with a radiation power of 7W would cause a maximum specific absorption rate (SAR) of 14W/kg (Uebayashi et al., 1985). In many countries, cellular telephones and cordless telephones have been in use for a long time. In these cases, the antenna is relatively close to the eye. Therefore, the potential for microwave hazards from portable communication systems has been focused on the eye. Corneal endothelial abnormalities have been observed in monkeys (Macaca fascicularis) after a 240 min. exposure to a 2.45 GHz continuous wave (CW) field at a power density of 20-30 mW/cm² (Kues et al., 1987). The eyes of 5 monkeys (Macaca fascicularis) were microwave-irradiated at a power density similar to that of Kues et al., without finding any abnormality in the corneal endothelia of the monkeys (Kamimura et al., 1994). Further investigations are necessary to clarify this discrepancy.

It has been reported that high-intensity microwaves can induce cataracts in the eyeballs of rabbits under systemic anesthesia with the local SAR being 136W/kg at 2.45GHz for 100 min. (Guy et al., 1975). These studies have attempted to determine if there is a hazardous effect of low-power density microwaves at 2.45GHz on the eye of a rabbit under lengthy exposure without anesthesia, with the contralateral eye serving as a control.

MATERIALS AND METHODS

Animal

Nine young adult female Japanese White rabbits, body weight 1.0-1.8kg, 10-12 weeks of age, were purchased from Japan Bio Supply Center (Tokyo, Japan), and were maintained in the animal center of Nippon Medical School (Tokyo, Japan). The rabbits were kept in a conventional animal room at 22°C and 60% rela-
tive humidity. The animals were fed a commercial diet (RC-4, Oriental Yeast Co., Ltd., Tokyo, Japan) and water ad libitum.

**Apparatus**

The microwave source was a microwave therapy apparatus (MR-1: ITO Chyotanpa Co., Ltd., Tokyo, Japan). The applicator was designed for specific use in this experiment. The tip of the antenna was cut short to let the irradiated wave converge in a short distance. The degree of convergence was adjusted to an area 1 cm in diameter and 1 cm in depth, which was confirmed by a temperature rise in the phantom material irradiated at 5 mm from the antenna for 15 min.

**Methods**

A schematic of the system is shown in Fig. 1. The distance between the applicator and the eyeball of the rabbit was 5 mm. The power level of radiation was 20 W at the power meter (NS-663B: DAIWA Industry Co., Ltd., Tokyo, Japan). Phantom material was used to measure the SAR according to the technique described by Guy et al. (1975) and Nojima et al. (1994). In order to obtain the theoretical SAR, the phantom material was used as an ideal alternative for the living organism. A model eyeball was molded from the phantom material packed in a vinyl bag and the temperature was measured under microwave irradiation with a fluoptic thermometer (FX8000-00: Anritsu Meter Co., Ltd., Japan), allowing us to obtain the effective temperature change without any physical effect of microwave irradiation on the thermometer.

The SAR was calculated by the following equation:

\[ \text{SAR (W/kg)} = (1/0.0143) \times \triangle T / \triangle t \]

\( \triangle T \): increment of the temperature (°C)

\( \triangle t \): irradiation time (min)

Although the SAR itself is determined by this method, actual temperature increment in the living animal would be modified by so-called heat sink phenomena. Thus, the temperature of the rabbit eye was measured in two distinctive ways. First, the temperature of an intact eyeball in 3 rabbits under microwave irradiation was measured at the corneal surface by fluoptic thermometer and recorded by a computer thermography system (CIR-310: Aivo Co., Ltd., U. S. A.). Second, the temperature was measured directly on the eyeball during CW irradiation by a fluoptic thermometer probe that was surgically implanted in the anterior chamber. All temperature measurements were conducted for 15 min.

A rabbit was placed in an acrylic box with the head outside and the eyeball was irradiated by 2.45 GHz CW microwave at 20 W for periods from 160 min. to 240 min. (Table 1). The right eyeball was irradiated; the left one served as the control. The rabbit was not anesthetized during irradiation. The eyeballs were kept intact except that the right one was irradiated. The rabbit could blink voluntarily during irradiation, so the cornea was not dry. We did not feel it was necessary to set up another group of sham-irradiated eyes for control, because the performance characteristics of the apparatus were restricted to a small area.

The eyeballs were examined under systemic anesthesia with ketamine hydrochloride (5 mg/kg, im) and xylazine (0.25 mg/kg, im) by a slit lamp (Model 30SL: Carl Zeiss, Germany) and a specular microscope (Model SP-1: Konan Co., Ltd., Kobe, Japan) immediately after and one week after irradiation. Any abnormalities were recorded by a camera attached to slit-

![Fig. 1. A schematic representation of the 2.45 GHz microwave exposure system.](image-url)
lamp and specular microscopes. The slit-lamp microscope and the specular microscope were used to examine the anterior parts as well as the corneal and endothelium, respectively.

We investigated the score of ocular lesions according to the method described by Draize et al. (1944).

RESULTS

The SAR measured by phantom material was 26.5W/kg based on the temperature increment between pre- and post-exposure of 5.7°C. Temperature of the eye at the corneal surface showed an average baseline temperature of 34.3 ± 1.5°C (mean ± S.D. : n=3) before exposure, and 37.3 ± 0.8°C (mean ± S.D.) after irradiation for 15 min. The initial temperature of the anterior chamber measured by the surgically implanted thermal probe was 37.5°C just prior to exposure. The temperature rose to 39.8°C within 2 min. after irradiation at 20W, then stayed constant at that temperature for the remaining exposure of 13 min. This experiment was carried out on only one rabbit, because the surgical trauma disturbed further ophthalmologic examination. The expected temperature increment based on the calculated SAR (26.5W/kg) was 5.7°C, whereas the actual rise in temperature of the corneal surface and the anterior chamber was 3.0 and 2.3°C, respectively. That the actual temperature was lower than the expected value would be explained by structural heterogeneity and homeostatic temperature regulation of the organism. The former would involve the different specific dielectric properties of each part of the structure. The latter may involve transmission of heat including radiation, conduction, and the convection and biological counteraction of thermal gain.

The results of the ophthalmologic examination are summarized in Table 1. Miosis (Photos 2-4) was observed in all rabbits within 15 min. of exposure. The post-exposure slit-lamp examination of 9 rabbits revealed miosis and pupillary congestion (Photos 3, 4) in all rabbits, keratoconuloma (Photos 3, 4) and corneal edema (Photos 3, 4) in 2 cases, endothelial cell detachment and floating in aqueous oculi (cell in the anterior chamber) in 5 cases, fibrin formation in the anterior chamber in 3 cases, and edema of the conjunctiva (chemosis: Photo 4) in 5 cases. These changes were transient and disappeared one week following exposure. The left control eye remained normal during the experimental observation, and was comparable to the right eye before irradiation (Photo 1).

As shown in Table 2, the average score of ocular lesions was 27.0 in the exposed eyes and 0 in all control eyes.

DISCUSSION

Cataract and heat-induced conjunctivitis have been observed in the rabbit eye irradiated by 2.45GHz field at 136W/Kg for 100 min. (Guy et al., 1975). Although the frequency was the same as that of the present study, the SAR was about 5.1 times higher than ours. We could not detect cataracts in any of the rabbits, which suggests a dose-effect for cataract formation. Cataract formation as a result of the thermal effect of 2.45-10GHz irradiation had been reported (Carpenter and Von Unmerson, 1968) in the rabbit, although the SAR was not checked. The miosis, pupillary congestion, bleb formation in the conjunctiva, cell

<table>
<thead>
<tr>
<th>Rabbit number</th>
<th>B.W. (Kg)</th>
<th>Exposure time(min)</th>
<th>Within 15 min. miosis</th>
<th>Pupillary congestion</th>
<th>Keratoconuloma</th>
<th>Corneal edema</th>
<th>Anterior chamber Cell</th>
<th>Fibrin</th>
<th>Chemosis</th>
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<td>220</td>
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<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
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<td>4</td>
<td>1.2</td>
<td>220</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
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<td>240</td>
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<td>+</td>
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<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
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<td>+</td>
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<td>+</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>+</td>
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</tbody>
</table>

Grade of pathological alteration; -, no change; +, slight; + +, moderate.
Photo 1. The rabbit eye before irradiation of the microwave. The pupilla is open in response to the light flash of the camera.

Photo 2. An eye of a rabbit (No. 2 in Table 1) after 30 minutes of irradiation with 2.45GHz at 26.5W/kg. The meiosis is seen. Other adnexa of the eyeball are para-normal.
Rabbit Eye Reversible Irritation by 2.45GHz Microwave.

Photo 3. Relatively mild alterations of an eye of No. 4 rabbit after 220 min. Irradiation conditions were the same as in Photo 2. The miosis, some blebs (arrows) in mildly swelled conjunctiva and pupillary congestion are apparent. The last 2 findings are suggestive of a thermal effect of microwave irradiation.

Photo 4. Relatively severe alteration of an eye of No. 7 rabbit after 182 min. of irradiation. Irradiation conditions were the same as Photos 2 and 3. Miosis, pupillary congestion, many bloody blebs (arrows) in the conjunctiva, and severe inflammatory swelling of the conjunctiva (chemosis) covering the iris are seen. The status is considered to have progressed further in comparison with that seen in Photo 3.
detachment and fibrin formation in the anterior chamber have never been described even at high power irradiation.

Because the miosis and pupillary congestion occurred in all the irradiated eyes in our study, a causal relation between microwave irradiation at 2.45GHz and pathologic conditions of the rabbit eye was significant. Another reason to support this relation is that the exposure was carried out without use of anesthetics, some of which may cause miosis. The mechanisms of microwave action which cause such pathological conditions are not fully known, although thermal effects may be involved. Other symptoms did not always occur in all cases, which suggests some individual differences in response to microwave irradiation. Although the pathological conditions may appear as a consequence of the microwave irradiation, again we do not know the basis for the individual difference.

In conclusion, ophthalmologic signs observed in the present study were transient, and the rabbits had recovered to normal one week after irradiation. However, we hesitate to state that 2.45GHz irradiation of the eye at 26.5W/Kg for 180 to 240 min. will not harm the rabbit eye. The reasons are: 1) That the mechanism(s) of microwave action on the rabbit eye is not fully understood; 2) that a dose-effect relation has not been determined precisely (it has not been known whether there is a threshold); 3) that the risk of repeated-dose or long-term effects has never been determined experimentally; and 4) that there may be differential biological effects related to the microwave frequency. These problems need to be clarified in future. However, it will take a long time.

Hazardous effects of microwave irradiation on the rabbit eye were clearly demonstrated by the lesion score with Draize's method. Therefore, more work is necessary to ensure that there is no danger to human beings from microwaves. The microwave environment has become more congested. Examples are widespread use of transceivers, as well as portable and cordless telephones. This equipment is utilized in the vicinity of users and in neighborhoods at local SAR levels up to 8 W/kg (by Japanese safety guideline), which is about a quarter that of the present irradiation condition. Overall exposure levels in casual life would be expected to be much less than that of the present experiment, but epidemiological data on high-frequency microwave irradiation are not available. Some concern has been expressed by the mass-media, although there is no experimental data to support such concern. If one is exposed to high power levels of microwaves for a long period under illegal or certain occupational situations, such concern may be valid. In the real field, there is a mixture of microwaves with different frequencies at unspecified SARs. Therefore, further studies on biological effect of the microwaves at different wave lengths should be carried out.

Table 2. Individual scores of ocular lesions by Draize's method.

<table>
<thead>
<tr>
<th>Rabbit number</th>
<th>Right (exposure)</th>
<th>Total score</th>
<th>Left (control)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cornea</td>
<td>Iris</td>
<td>Conjunctiva</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>10</td>
<td>14</td>
</tr>
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<td>10</td>
<td>12</td>
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</tr>
<tr>
<td>8</td>
<td>0</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>10</td>
<td>18</td>
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</table>

| mean | 27.00 | 0     |
| S.D. | 4.78  | 0     |

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REFERENCES


