# Thermal Computation Model of Rabbit Eye for Assessment of Ocular Effects Due to Microwave Energy

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## INTRODUCTION

There has been increasing concern about adverse health implication due to electromagnetic wave exposures. Various public organizations have established safety guidelines for EM wave exposures (e.g., ICNIRP 1998). For RF near field exposures, the guidelines limit peak spatial-average specific absorption rate (SAR). In the ICNIRP guideline, the averaging mass is 10 g and the limit is 2 W/kg. The rationale for this regulation is that thermal damage could occur in sensitive tissues under conditions of partial-body exposure.

Substantial attention has been paid to eye tissues, since it has been reported that RF energy causes a variety of ocular effects, including cataracts due to high-intensity exposure. Guy et al. investigated the effect of microwave heating on the lens in albino rabbits under systemic anesthesia [1]. The threshold power density for inducing cataract formation was 150 mW/cm$^2$ for the time duration of 100 min. On the other hand, Kamimura et al. reported that no abnormality was found on corneal endothelial cells in the same kind of study without anesthesia [2]. We attributed to one of the main difference for this difference to the application of anesthesia on the rabbit. Note that much higher temperatures were observed in the eyes of anesthetized rabbits than in the non-anesthetized rabbits [3].

In order to assess this problem thoroughly, we have developed a computational model of a rabbit [4]. The developed model was based on the conventional bioheat equation, while it takes into account the whole rabbit body. Additionally, this computational model uses an active blood flow model, which is varied with local and global temperatures in the rabbit. It is worth noting that an eye was assumed as an object thermally isolated from the head [5], and this simplified model has been used until recently.

In this paper, the procedures for developing this thermal computation model of rabbit are reviewed in detailed. The temperatures calculated using this model are compared with measured ones.

## RABBIT PHANTOM AND COMPUTATIONAL METHOD

### Rabbit Phantom

We have developed an anatomically-based rabbit phantom with the resolution of 1 mm. This was constructed on the basis of X-ray CT images, which were taken at Kanazawa Medical University, Japan. It is noteworthy that the thickness of most eye tissues, such as retina, choroid, and so forth are smaller than the spatial resolution of the phantom. Thus, retina, choroid, and sclera are considered as a mixed tissue, and their average electrical and thermal constants are used in our calculation. Similarly, iris and cilaiary body are treated as a tissue. The developed model is comprised of 12 tissues: skin, muscle, bone fat, brain, CSF, aqueous, vitreous, retina/choroid/sclera, iris/cilaiary body, lens, and cornea. The mass of the left eye, on which microwave is irradiated, is 3.1 g.

**FDTD method**

The FDTD method is used for investigating EM power absorbed in the rabbit phantom. For the truncation of computational region, we adopt perfectly matched layers for the absorbing boundary. In order to incorporate the rabbit model into the FDTD scheme, the dielectric properties of tissues are required. They are determined with the aid of the 4-Cole-Cole extrapolation.

**Temperature Calculation**

Our formula for temperature calculation allowing for thermoregulatory mechanism is mainly borrowed from the papers [6, 7]. For calculating the temperature increase in the rabbit phantom, the bioheat equation is used. It should be noted that the effect of sweating is neglected in our discussion, since this mechanism is negligible for rabbits, unlike humans.

**Determination of Thermal Parameters**

Specific heat, thermal conductivity, and the term associated with blood flow are mainly borrowed from [9], while metabolic heat productions are modified for taking into account the physiology of rabbits. The specific heat and thermal conductivity of tissues are interpolated on the basis of water content. Note that the water content of tissue can be roughly estimated from electrical constants. The blood flow in the vitreous, aqueous, and lens can be considered as nonexistent. Also, the blood flow in the cornea is considered negligible as compared with that in the retina/choroid/sclera and iris/cilaiary body. Then, this value is also assumed as zero. Note that the blood flow in the retina and choroid are comparable to and 10-20 times larger than that in the brain. The blood flow in the fat and vitreous humor, which exist close to the retina/choroid/sclera, is negligible. The thickness of the retina, choroid, and iris are 0.1-0.3, 0.1-0.2, and 0.6 mm, respectively. Based on these parameters, the term associated with blood flow in the retina/choroid/sclera is interpolated to 80,000-16,000 W/m$^3$ for the resolution of 1 mm. Note that the thickness of the retina and choroid is dependent on the position, and it becomes largest around the optical nerve. In our model, the retina/choroid/sclera is further classified into two parts on the basis of the amount of blood flow. For the retina/choroids/sclera which is close to the lens, 80,000 W/ m$^3$ is assigned, while 160,000 W/ m$^3$ is assigned for the part which is close to the nerve.

First, the convection coefficient between the skin and air is discussed. Now we considered the convection in the skin, the evaporation effect is negligible at normal room temperature. Temperature in the skin located at the top of the head is measured, and compared with calculated value. For two rabbits, the value was 2.5-3.5 W/m$^2$/ $^o$C (See Fig.1). Note that small variation of temperature ±0.3 $^o$C is observed even at thermally steady state. From this result, the effective area of rabbit skin can be determined by 0.3. Note that this is much smaller than that of human (about 1), which is attributed to fur on the skin.

Next, the convection coefficient between the cornea and air is discussed. This value should include the following effects: i) evaporation of the tear film, ii) convective exchange with the air, and iii) radiative exchange with the surrounding objects. It is worth noting that the rate of evaporation would be affected by at least two factors: tears due to the insertion of probes and the application of saline solution with room temperature in order to prevent the eye surface from becoming dry. In our experiment, this value was 20-50 W/m$^2$/$^o$C and dependent on individual rabbit eye. Note that this value was 20 W/m$^2$/$^o$C in the measurement by another group [5].

Basic procedure for deriving thermal constants of tissues was summarized. It should be noted that these constants are related with each other: e.g., the value of blood flow in the choroid affects the convection coefficient between the eye and air. The values presented in this section were determined iteratively.

## COMPARISON BETWEEN COMPUTED AND MEASURED TEMPERATURES

Fifteen minutes after the temperature probes were inserted into the eye (after the anesthesia of the eye had worn out), the eyes were exposed to 300 mW/cm$^2$ for 1 h. Then, there was a cooling time of 1 h. Fifteen minutes after administration of systemic anesthesia, the rabbit was again exposed to 300 mW/cm$^2$ for 1 h. The schematic of this experiment is shown in Fig. 2. Temperature variations in the rabbit eye are illustrated in Figs. 3 for the cases without and with anesthesia, respectively. Good agreement is observed in both cases. Note that in our computation, the blood flow is considered as variables with local and global temperatures in the case without anesthesia, while assumed as constant on the basis of the result in [3].

## SUMMARY

This paper presented detailed procedures for developing this thermal computation model of rabbit. This computational model is validated by comparing computed and measured results.

## REFERENCES

[1] A. W. Guy, J. C. Lin, P. O. Kramar, and A. Emery, “Effect of 2450-MHz radiation on the rabbit eye,” IEEE Trans. Microwave Theory & Tech., vol.23, no.6, pp.492-498, 1975.

[2] Y. Kamimura, et al. “Effect of 2.45 GHz microwave irradiation on monkey eyes,” IEICE Trans. Comm., vol.E77-B, no.6, pp.762-765, 1994.

[3] M. Kojima et al., “Influence of anesthesia on ocular effects and temperature in rabbit eyes exposed to microwaves,” Bioelectromagnetics, vol.25, no.3, pp.228-233, 2004.

[4] A. Hirata et al., ICNIRP Workshop, 2004.

[5] J. J. W. Lagendijik, “A mathematical model to calculate temperature distributions in human and rabbit eye during hyperthermic treatment," Phys. Med. Biol., vol.27, pp.1301-1311, 1982.

[6] R. J. Spiegel, "A review of numerical models for predicting the energy deposition and resultant thermal responses," IEEE Trans. Microwave Theory Tech., vol.32, pp.730-746, 1984.
[7] M. Hoque and O. P. Gandhi, "Temperature distributions in the human leg for VLF-VHF exposures at the ANSI recommended safety levels," IEEE Trans. Biomed. Eng, vol.35, pp.442-449, 1998.

Fig. 1. Photograph when measuring temperature of skin at the rabbit head.

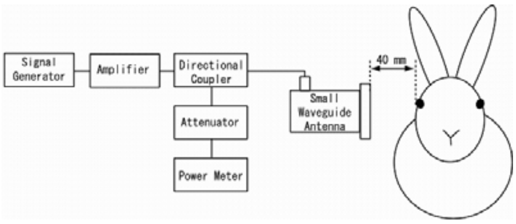


Fig. 2. Schematic explanation of rabbit eye exposedto 2.45 GHz microwave.

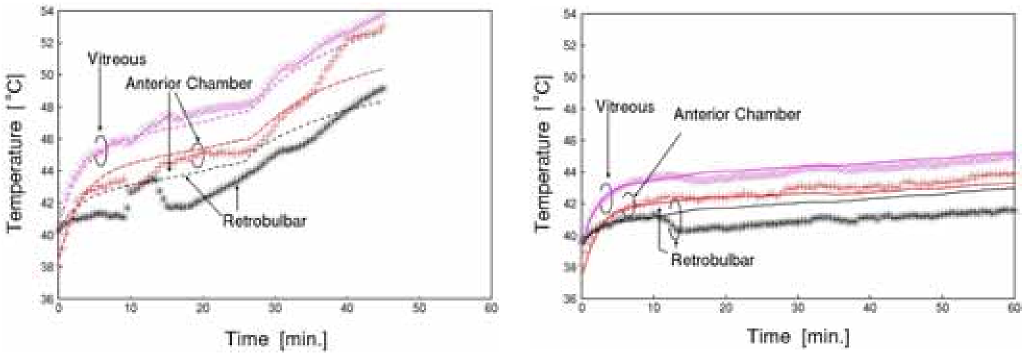


Fig. 3. Time evolution of temperature in the rabbit eye: with anesthesia (left) and without anesthesia (right).