Numerical Simulation of Heat Transport for Rabbit Eye Exposed to Millimeter Wave Considering Fluid Dynamics within Anterior Chamber

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Abstract

The ocular damage caused by MMW exposure is highly depends on the temperature elevation in the anterior part of the ocular tissue with the complicated structure. Especially, aqueous humor in the anterior chamber affects the nature of heat transport under the MMW exposure. In this study, we have originally developed the coupled analysis system on electromagnetic field (EMF) and heat transport (HT) including the fluid convection model. As an example of non-linear HT analysis, distributions of temperature elevation and aqueous humor flow are calculated in the condition of 75GHz, 150mW/cm^2 MMW exposure.

1. Introduction

Interactions between millimeter-waves (MMWs: 30 GHz-300GHz) and eyes are complex, and it causes various kind of damage in ocular tissue depending on frequency and irradiation power density. That diversity of ocular damage is caused by the nonlinear heat transport due to the aqueous humor within anterior chamber. We are conducting MMW exposure experiment with rabbit eye to obtain clues to heat transport mechanism. The purpose of this study is to investigate the heat transport mechanism in the front region of ocular tissue under MMW exposures by computer simulation in the condition of actual exposure experiments. The coupled analysis system has been developed to link electromagnetic field (EMF) simulation and heat transport (HT) simulation including fluid convection model. The high-resolution anatomical rabbit eye model has been also developed to consider actual condition. Heat transport is solved from 40GHz to 95GHz to clarify the dependency of the three-dimensional temperature distribution on the frequency change.

2. Coupled analysis system

Coupled analysis system on electromagnetic field (EMF) and heat transport (HT) including fluid convection has been originally developed to investigate the heat transport mechanism causing temperature elevation. Figure 1 shows the structure of EMF-HT coupling analysis system. 3D incident EMF distributions generated by the lens antenna is reconstructed from actually measured 2D electric field distribution by the plane wave spectrum (PWS) [1] method. Induced EMFs in the rabbit eye is calculated from the reconstructed 3D EMF by the scattered-field FDTD method. And HT is performed by the simplified maker and cell (SMAC) method to obtain time dependent temperature and flow velocity distribution. Specific absorption rate (SAR) is given to the heat transport code as the heat source. Therefore heat transport equations are coupled with Maxwell's equation through the heat source term. In EMF and HT analysis, the high-resolution anatomical rabbit eye model as shown in Fig. 2 is used to consider actual exposure condition. Spatial resolutions are 50μm and 100μm for EMF and HT analysis, respectively.

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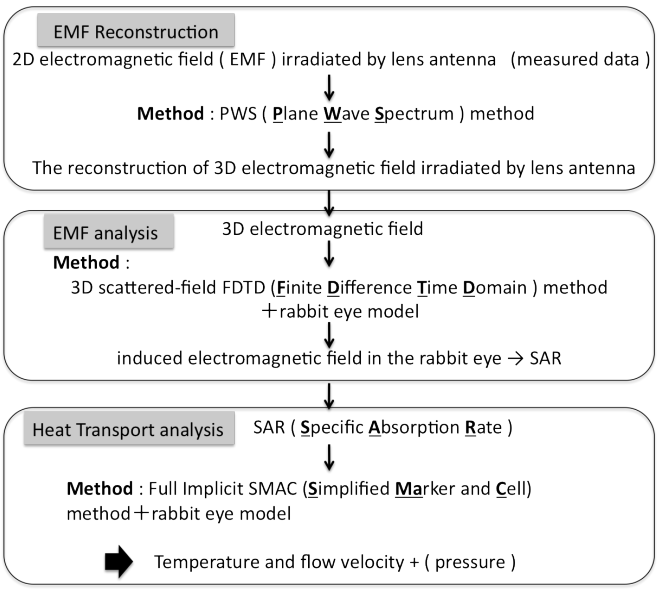

Fig. 1. Structure of electromagnetic field and heat transport coupling analysis system.

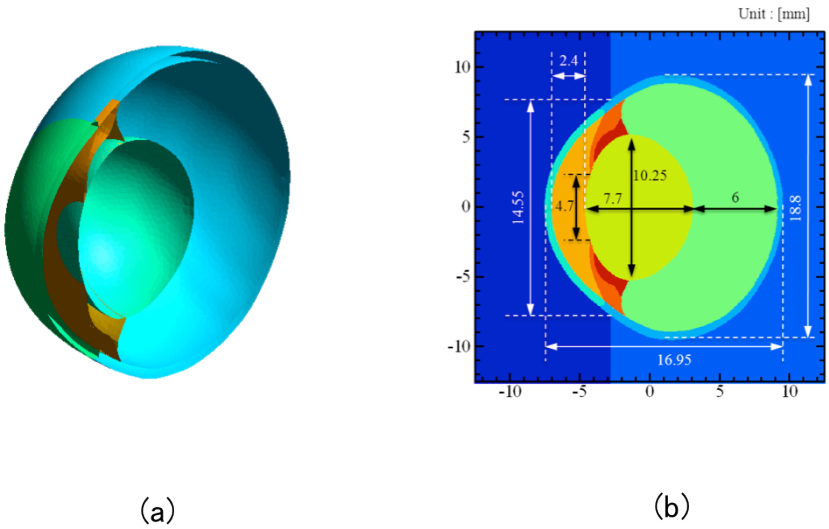

Fig. 2. High-resolution rabbit eye model. (a) 3D CAD model constructed from actual measured data of rabbit eyes, (b) Voxel model of 50μm spatial resolution for finite difference scheme.

4. Result

Figure 1 shows an example of HT simulation considering the fluid dynamics within the anterior chamber. Exposure condition is as follows. Frequency and spatial averaged power density are 75GHz and 150mW/cm^2, respectively. Figure 1 indicates temperature and flow distributions at 6 min after the beginning of MMW exposure. This is the rear view of the eye. Color image of vertical cross section indicates temperature distribution. Vectors denote flow direction and color of vectors is flow velocity of aqueous humor.

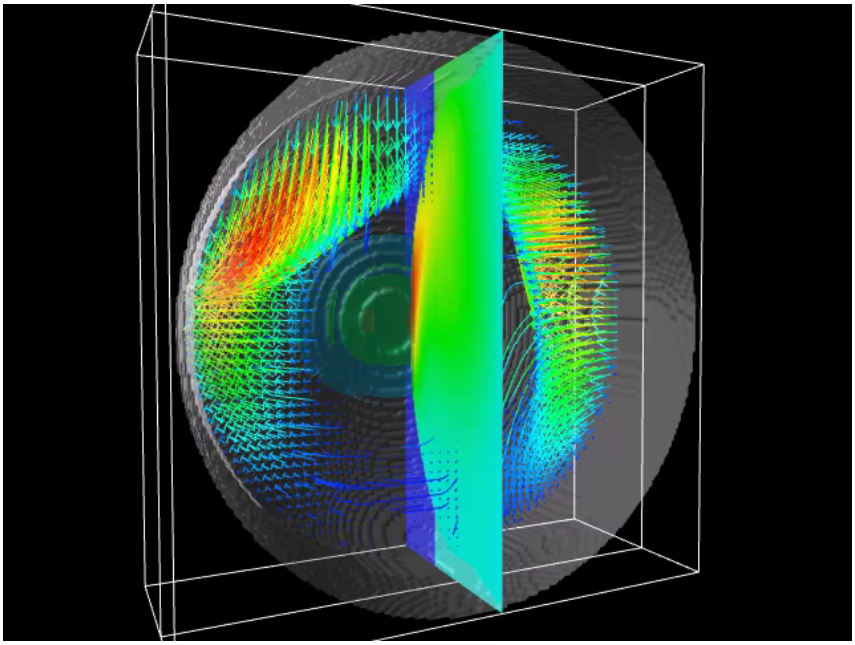

Fig. 2. A example of 3D heat transport simulation. Frequency and power density of incident MMW is 75GHz and 150mW/cm^2, respectively. This image shows 6 min after the beginning of exposure. A color image of vertical cross section indicates temperature distribution, and vectors denote flow velocity distribution.

To investigate the dependence on the frequency and the incident power density, parameter sweeping simulation is performed. In the presentation, we will show the dependence of heat transport characteristics on the frequency and incident power density in temperature distribution and flowing distribution.

5. Conclusion

We have developed coupled EMF and HT analysis system for the dosimetry of MMW exposure for rabbit eye. High-resolution anatomical rabbit eye model has been also developed to consider actual condition of exposure experiment. As an example of computer simulation result, 3D temperature and flowing distributions are shown in the condition of 75GHz, 150mW/cm2 exposure. It is found that, temperature elevations in cornea and lens are affected by the convectional heat transport in the anterior chamber.

6. Acknowledgments

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7. References

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