Computational Analysis on Induced Current Density and Electric Field in a Pregnant Woman Model Due to Intermediate Frequency Magnetic Fields

Yukihisa Suzuki[†1], Kei Maruyama[‡*], Kanako Wake[*], Soichi Watanabe[*], Masao Taki[†], Osamu Hashimoto[‡]

[†] *Department of Electrical & Electronic Engineering, Tokyo Metropolitan University*
1-1 Minamiosawa, Hachioji ,Tokyo, 192-0397, Japan
[1] y_suzuki@tmu.ac.jp

[‡] *Graduate School of Science and Engineering, Aoyama Gakuin University*

[*] *National Institute of Information and Communications Technology*

***Abstract*— Induced current densities and induced electric fields within a pregnant woman and the fetus were calculated by using the high definition anatomical model of Japanese pregnant woman. The pregnant woman model was exposed to uniform magnetic fields at 20 kHz for three axis directions. The distributions of the induced current density and the induced electric field were presented for all conditions as to direction of the magnetic flux density. The distributions of the induced current density were different only in the region of the abdomen between pregnant woman models and the non-pregnant woman model. No significant differences are observed in both two models in other region. The distributions of the induced electric field were almost the same tendency for two models in any cases of the incident magnetic field directions.**

Key Words: pregnant woman model, intermediate frequency, induced current density, induced electric field, dosimetry

I. INTRODUCTION

There has been increasing appliances using magnetic field in the intermediate frequencies (IFs) from 300 Hz to 10 MHz [1]. Induction heating (IH) hobs, electronic article surveillance (EAS) systems and RFID are examples of the appliances. Since these devices are often used in the proximity of the human body, human beings are exposed to magnetic fields with intermediate frequency. It is required to assess the safety comparing with guidelines and standards of EMFs.

There are a few studies on the dosimetry of the induced current density and the induced electric field in the IF band. World Health Organization (WHO) recommended further research on IF band in the Environmental Health Criteria [2], because of the lack of data in this area. The dosimetry on the pregnant woman and the fetus is one of the important issues for the EMFs safety in the IF band. However there are also few studies on the dosimetry of the pregnant woman and the fetus. WHO mentioned importance of the calculation of the induced current densities and electric fields in pregnant and in the fetus with appropriate anatomical modeling.

Numerical dosimetries on the pregnant woman have been recently reported by several groups. Kainz *et al.* [3] investigated the current densities and the specific absorption rates (SARs) for pregnant women exposed to hand-held metal detectors. Dimbylow [4] has developed the hybrid voxel-mathematical models of pregnant woman, and calculated the induced current densities and the electric fields. However, these studies do not consider the anatomical structure with regard to a fetus.

The purposes of this paper are as follows. One is to investigate the induced current density and the electric field in a pregnant woman by using Japanese pregnant woman model with anatomical structure [5]. Second is to compare the induced quantities between pregnant woman and non-pregnant woman.

II. PREGNANT WOMAN MODEL

A. *Numerical model*

An anatomical human model of whole-body pregnant woman [5], which has been provided by National Institute of Information and Communications Technology (NICT), was used for evaluation of the induced current density and the induced electric field. This model was based on the anatomical voxel human model of non-pregnant woman [6] and the abdominal MR images of 26-week-pregnant woman.

B. *Electrical conductivity of the tissues*

The Electrical conductivity is one of the important factors for the dosimetry of the induced current density and electric field, because the conductivities of the tissues much affect the solutions. The 4-Cole-Cole dispersion model developed by Gabriel *et al* [7] was employed in this study. That is widely used in the dosimetry of the electromagnetic field exposure for the human. However, there have been few study on the electrical property of the inherent tissues of the pregnant woman, especially the fetal tissues. Thus in this paper, we assumed these values on the basis of the previous reports [4],[8],[9].

The conductivity of the amniotic fluid was referred from the report by De Luca *et al* [10], which is the obtained from the measurement of the electrical conductivity for different 85 samples in various gestation weeks. It was supposed that the conductivity of the placenta was the same value as the blood of mother, i.e. the value of adult. The most part of the placenta consists of the blood of the mother. It was also assumed that the conductivities of the fetal tissues have the same values of the adult. The fetal brain was the averaged value of the grey matter and the white matter of the adult, and the fetal eyes was the same value of the conductivity of the eyes of adult. The conductivity of the fetal body was whole-body average value of adult model that is weighted by the volume ratio of each tissue.

III. Calculations of the Induced Current Density and Electric Field

A. Numerical analysis method

In order to calculate the induced current densities and the induced electric fields, the impedance method [11] was employed. Individual tissues and organs of the human are assumed by the cubic voxel in which each edge is applied the impedance in this method. Induced currents of all edges of the voxels were calculated with the impedance method. Induced current densities were obtained by dividing the induced current by cross section Δl^2. Here, Δl is grid size of voxel, i.e. 2mm. The induced electric field was calculated by dividing the induced current density by the conductivity given within the voxel.

B. Incident magnetic fields

Three directions of the incident magnetic fields were assumed along the axis directions, from above (TOP), from the side (LAT) and from the front (AP) in this investigation. The induced current density and the induced electric field depend on the directions of incident magnetic fields, thus the basic three directions of these incident magnetic fields were considered. The frequency of the magnetic field is assumed 20 kHz as an example of the intermediate frequency. This frequency band is used for IH hobs in heating operation. The

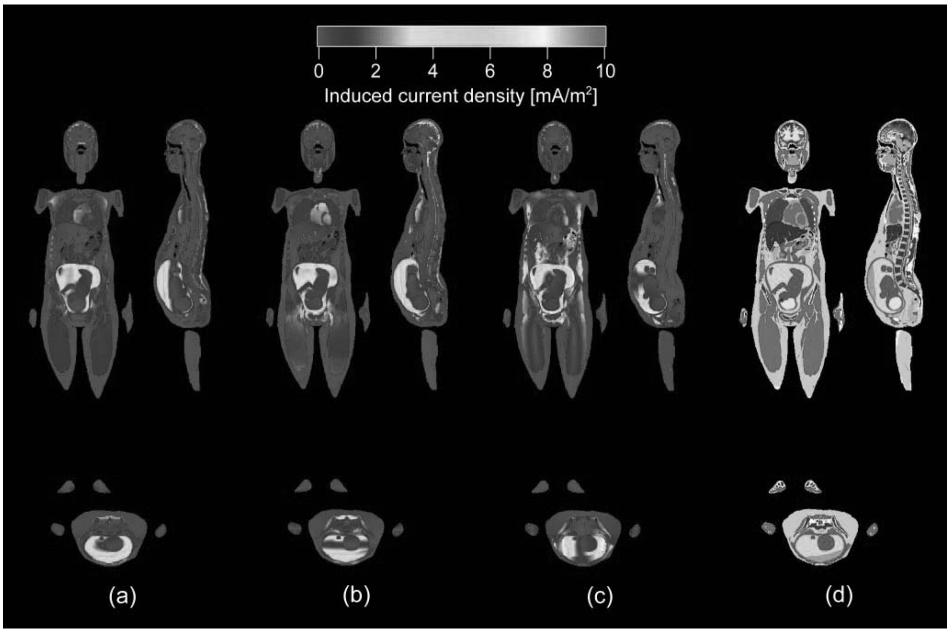

Fig.1 Distributions of the induced current density within a pregnant woman model. Directions of the incident magnetic fields are (a) TOP, (b) LAT, and (c) AP. (d) is the cross-section view of the pregnant woman model.

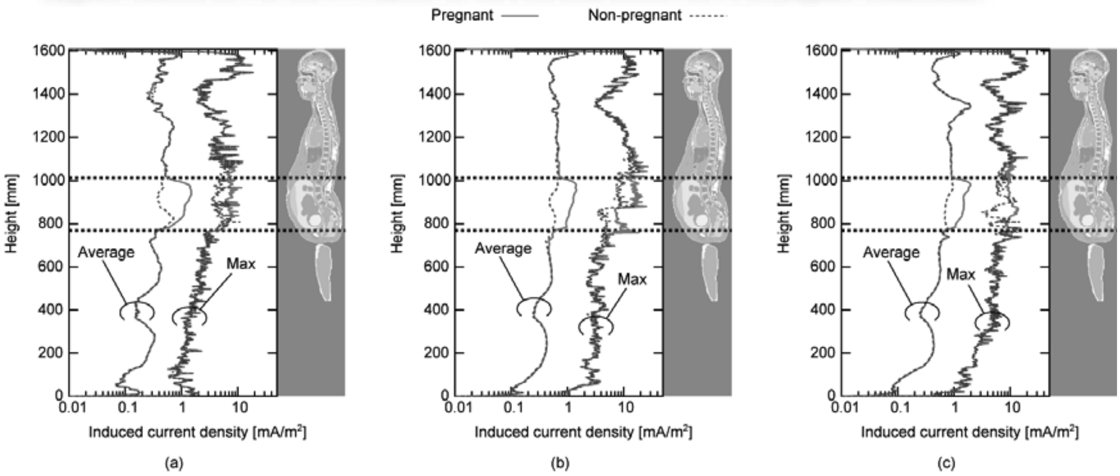

Fig.2 Distributions of maximum and averaged value of the induced current density along the height. The area between thick dashed lines is the existing region of the amniotic fluid for the pregnant-woman model. Incident magnetic field directions are (a) TOP, (b) LAT, and (c) AP.

magnetic flux density was set at 1 μT.

IV. RESULTS

A. Distributions of the induced current density

Figure 1 shows the distributions of the induced current densities of cross-section area for three directions of incident magnetic fields. As seen from the figure, the induced current density in the amniotic fluid is large. The amniotic fluid has the high conductivity of 1.27 S/m comparing with other surrounding tissues, e.g. muscle conductivity is 0.35 S/m and stomach conductivity is 0.53 S/m. The induced current densities within amniotic fluid tend to be larger than other tissues.

In Fig. 1 (b), the induced current density around the spinal chord is large than the other tissues, because the cerebral spinal fluid (CSF) exists around this area. In the case of LAT exposure, the induced current flows along to the backbone, hence the CSF becomes the main current path. Therefore the induced current density of LAT exposure was the largest in all cases.

Figure 2 shows the distributions of the maximum value and the averaged value of the induced current density in the horizontal plane at any height. Incident magnetic field direction is (a) TOP, (b) LAT, (c) AP. The red solid lines indicate the induced current densities of the pregnant woman model, and blue dashed lines indicate those of the non-pregnant woman model. "Average" denotes the value averaged over a horizontal cross section, and "Max" denotes the maximum value in the horizontal cross section. Thick dashed lines at 800 mm and 1000mm height are the bottom and top of the amniotic fluid region of the pregnant-woman model.

The distributions of induced current density in the pregnant-woman model and the non-pregnant woman model are different in the height between 800 mm and 1000 mm at which the amniotic fluid exist. The non-pregnant woman model does not have the tissue of amniotic fluid, thus the induced current densities of the pregnant-woman model are larger than those of the non-pregnant woman model in this region. In the case of "Average", the maximum ratio of the induced current density of the pregnant-woman model is 3.7 times larger than that of the non-pregnant woman model. The same tendency is observed in the case of "Max". Significant differences are not observed between two models except the region of 800-1000 mm.

B. Distributions of the induced electric field

Figure 3 shows the induced electric field within the pregnant woman model. The directions of the magnetic field are (a) TOP, (b) LAT, (c) AP. From the figure, the induced electric field of fat tissue tends to be larger than other tissues. The higher electric field obtained in the fat existed between high conductivity tissues. In the case of AP exposure (see. Fig. 3 (c)), it is remarkable that the electric field in the fat between amniotic fluid and muscle, and in the fat between two muscles are larger than other tissues. The same tendency was observed in the case of non-pregnant woman model. This tendency can explain by following reason. The induced current always flows continuously in the human body. If the low conductivity tissue lies orthogonal to the current flow direction, the induced current was interrupted. In this situation, the electric field becomes larger in order to keep the current flow.

The distributions of the induced electric field in the horizontal plane at any height are shown in Fig.4. Incident magnetic field direction is (a) TOP, (b) LAT, (c) AP. Red

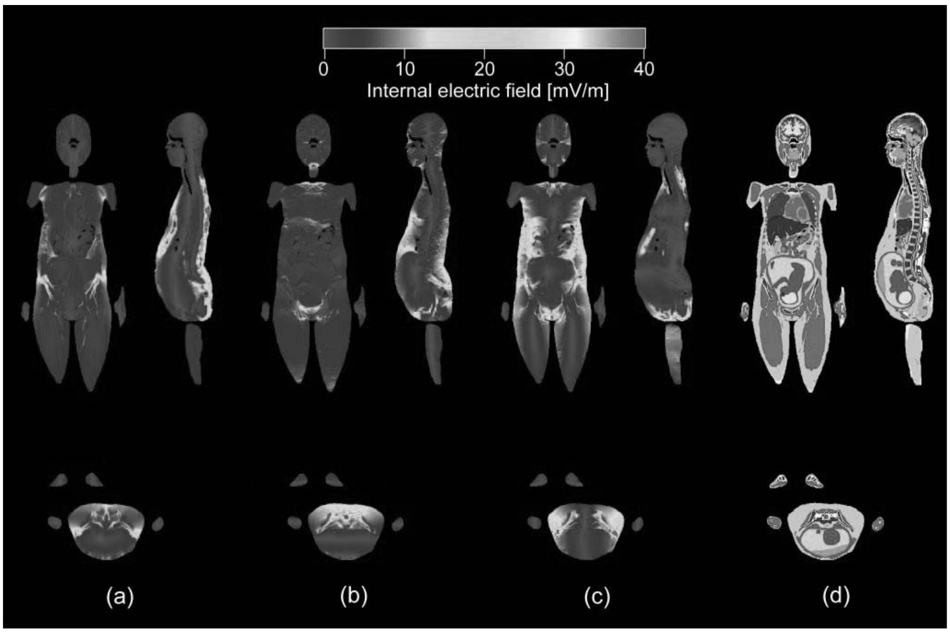

Fig.3 Distributions of the induced electric field within a pregnant woman model. Directions of the incident magnetic field are (a) TOP, (b) LAT, and (c) AP. (d) is the cross-section view of the pregnant woman model.

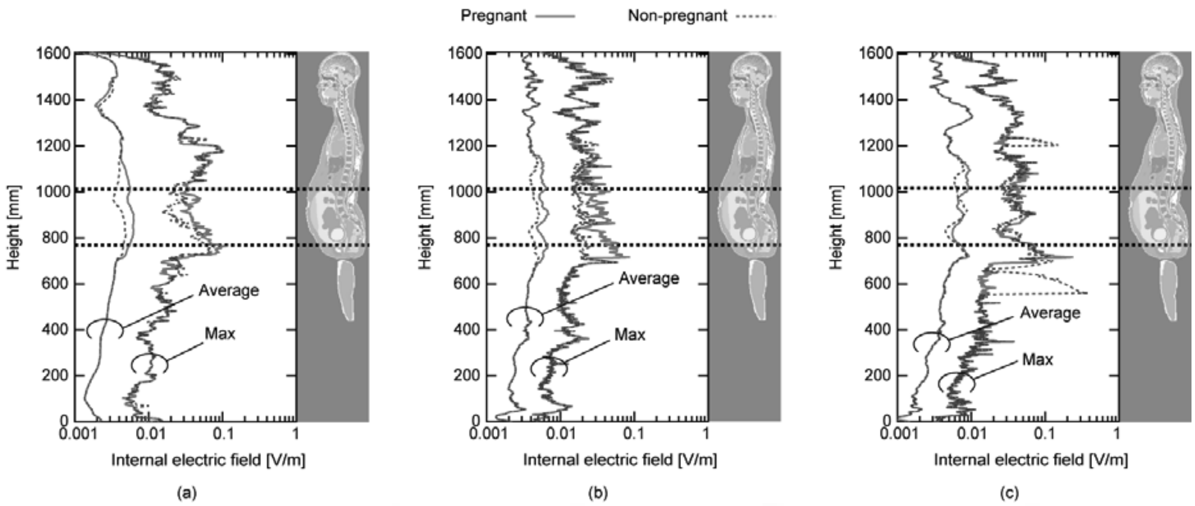

Fig.4 Distributions of maximum and averaged value of the induced electric field along the height. The area between thick dashed lines is the existing region of the amniotic fluid for the pregnant-woman model. Incident magnetic field directions are (a) TOP, (b) LAT, and (c) AP.

solid lines indicate the induced electric field of the pregnant-woman model, and blue dashed lines indicate those of the non-pregnant woman model. Two thick dashed lines is the top and bottom height of the amniotic fluid of the pregnant-woman model.

The difference of the distribution between two models is observed in the height from 700 mm to 1000 mm in the abdomen. The induced electric field tends to be larger in fat between amniotic fluid and muscle as shown in Fig.4. The region observed different electric field values is wider than the region existing the amniotic fluid. In the Fig.4 (c), it is found that the maximum value of the non-pregnant woman model is much large value in the height of 500 mm to 700 mm. These singular values are caused by the staircase approximation of the human model. The details regarding the stair-casing error were reported by Dawson *et al.*[12].

V. Conclusion

This paper presents the investigation of the induced current density and the induced electric field within a pregnant woman by using whole body anatomical pregnant woman model with fine resolution. The induced current density and the induced electric field were compared between pregnant woman and non-pregnant woman.

The distributions of the induced current density were different only in the region of the abdomen between pregnant woman models and the non-pregnant woman model. No significant differences are observed in both two models in other region. The distributions of the induced electric field were almost the same tendency for two models in any cases of the incident magnetic field directions. The high electric fields were observed in the tissues in skin or fat.

Acknowledgments

Parts of this work were carried out using the vector supercomputer SX-8R (NEC) at the National Institute of Information and Communications Technology.

References

[1] E. Litvak, *et al.*, “Health and Safety Implications of Exposure to Electromagnetic Fields in the Frequency Range 300 Hz to 10 MHz”, *Bioelectromagnetics*, **23**, pp. 68-82, 2002.

[2] WHO, “Extremely Low Frequency Fields”, *Environmental Health Criteria Monograph*, No. 238, 2007.

[3] W. Kainz, *et al.*, “Calculation of induced current densities and specific absorption rates (SAR) for pregnant women exposed to hand-held metal detectors”, *Phys.Med. Biol.* **28**, pp. 2551-60, 2003.

[4] P. Dimbylow, “Development of pregnant female, hybrid voxel-mathematical models and their application to the dosimetry of applied magnetic and electric fields at 50 Hz”, *Phys. Med. Biol.*, pp. **51** 2383-2394, 2006.

[5] T. Nagaoka, *et al.*, “An anatomically realistic whole-body pregnant-woman model and specific absorption rates for pregnant-woman exposure to electromagnetic plane waves from 10 MHz to 2 GHz”, *Phys. Med. Biol.*, **52**, pp. 6731-6745, 2007.

[6] T. Nagaoka, *et al.*, “Development of realistic high-resolution whole-body voxel models of Japanese adult males and females of average height and weight, and application of models to radio-frequency electromagnetic-field dosimetry”, *Phys. Med. Biol.*, **49**, pp. 1-15, 2004.

[7] S, Gabriel, *et al.*, “The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues”, *Phys. Med. Biol.*, **41**, pp. 2271–2293, 1996.

[8] R. Cech, *et al.*, “Fetal exposure to low frequency electric and magnetic fields”, *Phys. Med. Biol.*, **52**, pp. 879-888, 2007.

[9] R. Cech, *et al.*, “Current densities in a pregnant woman model induced by simulataneous ELF electric and magnetic field exposure”, *Phys. Med. Biol.*, **53**, pp. 177-186, 2008.

[10] F. de Luca, *et al.*, “Use of low-frequency electrical impedance measurements to determine phospholipid content in amniotic fluid”, *Phys. Med. Biol.*, **41**, pp. 1863-1869, 1996.

[11] N. Orcutt and O. P. Gandhi, “A 3-D impedance method to calculatepower deposition in biological bodies subjected to time varying magnetic field”, *IEEE Trans.Biomed. Eng.*, **35**, pp. 577–583, 1988.

[12] T. Dawson *et al.*, “Accuracy evaluation of modeling of low frequency field interactions with the human body”, *ACES J.*, **16**, pp.162-72, 2001.