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# Specific Absorption Rate in Mothers and Fetuses in the Second and Third Trimesters of Pregnancy

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*Abstract* – **Recently, there has been increasing concern regarding the safety of exposure to RF electromagnetic fields in pregnant females and their fetuses. In this study, we acquired fetal magnetic resonance imaging at 20 26 and 29 weeks from a healthy volunteer of pregnancy and developed the pregnant female models at those weeks of pregnancy by combining the fetal models constructed on the basis of the fetal MRI data and an existing non-pregnant female model. We also estimated the specific absorption rates in those models for whole-body exposure to radio-frequency electromagnetic fields using the finite-difference time-domain method.**

*Index Terms* – **Specific absorption rate, Finite-difference time-domain method, Computational human model, Mother and fetus, Numerical Dosimetry.**

## I. INTRODUCTION

Concerns regarding the adverse health effect of human exposure to radio-frequency (RF) electromagnetic fields (EMFs) have been increasing. The safety of RF-EMF is evaluated based on the specific absorption rate (SAR) which is the amount of RF energy absorbed per unit weight of the body and is used as a measure of the thermal effects of RF-EMF exposure [1], [2]. The SAR is defined by the following equation:

$$\mathrm{SAR} = \frac{\sigma}{\rho} E^2 \qquad [\mathrm{W/kg}] \qquad (1)$$

where $\sigma$ is the conductivity of the tissue [S/m]; $\rho$, the density of the tissue [kg/m$^3$]; and $E$, the electric field strength (r.m.s.) inside the tissue [V/m].

Recently, we have carried out a detailed SAR estimation by numerical simulation using anatomically realistic computational human models. Most of the models have been developed on the basis of medical image data of entire human bodies [3-5]. However, developing a whole-body pregnant female model from medical imaging data is not simple because of the difficulty to obtain whole-body images for ethical considerations. Therefore, the whole-body pregnant female models have constructed by combining a model of fetus including gestational tissues, constructed on the basis of the abdominal MRI (Magnetic Resonance Imaging) data acquired from pregnant woman, and that of non-pregnant female, deformed the abdomen by applying image processing techniques [6].

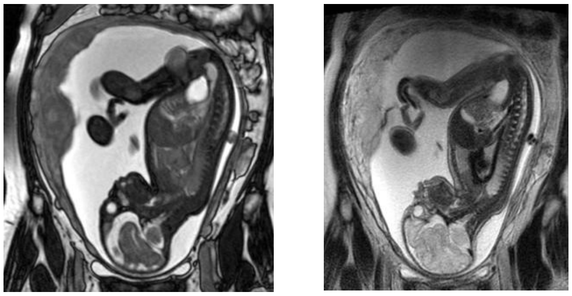
Anatomical structures of gestational tissues including fetal tissues are different depending on the pregnancy stage. Therefore, the pregnant female models at various gestational ages are required. There are a few reports on the development of pregnant female models at different gestational ages [7-9]. However, anatomical structures of the fetuses in the pregnant female models are not necessarily realistic.

In this paper, we present the outline of new pregnant female models with anatomically realistic fetal models in the second and third trimesters of pregnancy and demonstrate the specific absorption rates in those models exposed to vertically polarized EMFs in very-high-frequency (VHF) and ultra-high-frequency (UHF) bands using the finite-difference time-domain (FDTD) method.

## II. DEVELOPMENT OF PREGNANT FEMALE MODELS

### A. Fetal MRI acquisition

Fetal MR images were taken using a 1.5 T MRI scanner in the Kanagawa Children's Medical Center (KCMC). In this study, MRI sequences were selected the 3D-ture-FISP (Fast Imaging with State Precession) and the BLADE as shown in Fig. 1. Imaging plane was coronal to pregnant woman. Acquisition times of 3D-ture-FISP (Fast Imaging with State Precession) and BLADE are 13 seconds × 3 times and 4 minutes respectively.



3D-ture-FISP image BLADE image

Fig.1. Fetal MR images.

### B. Construction of fetal models

Segmentations of the gestational tissues including fetal tissues were actually performed on the basis of 3D-ture-FISP images. BLADE images were used as reference images for identifying the gestational tissues from the 3D-ture-FISP images. Firstly, the image noise was removed by a smoothing filter processing. Next, semiautomatic approximate segmentation was performed by identifying the parts that could be classified relatively easily using basically image segmentation methods such as 3D region growing. And then, detailed segmentation was manually edited by medical staffs using voxel edit software (SliceOmatic ver. 4.3).

### C. Development of pregnant female models

A Japanese adult female model was used as maternal models of the fetal models. The abdomen of the model was expanded on the basis of the abdominal shapes of the fetal MR Image. The deformation performed by using free-form deformation (FFD) technique [10], and pregnant female models were developed by combining the new developed fetal models and the deformed maternal models.

## III. CHARACTERISTICS OF THE PREGNANT FEMALE MODELS

We constructed three fetal models at gestational ages of 20, 26 and 29 weeks on the basis of fetal MR images from a volunteer as shown in Fig. 2. The developed models consist of about 20 different tissue types including amniotic fluid, placenta, umbilical cord, brain, CSF (cerebrospinal fluid), eyeball, lens, lung, stomach, liver, heart, kidney and intestine. The fetal models are composed of voxels of approximately 0.74 × 0.74 × 0.74 mm$^3$. On the other hand, the original voxel size (i.e., spatial resolution) of the maternal models is 2 × 2 × 2 mm$^3$. Therefore, in this study, the voxel sizes of the fetal models were rescaled to 2 × 2 × 2 mm$^3$. The fetal models were fitted in the abdomen of the maternal models. Figure 3 shows the pregnant female models we developed. These models consist of over 70 different tissue types.

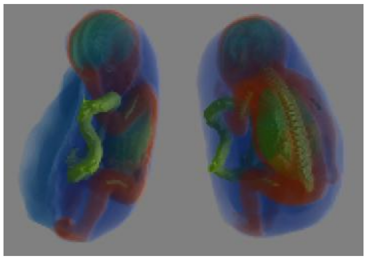


Fig.2. Example of fetal models (26 weeks).

Fig.3. Sectional images of the anatomical pregnant female models.

## IV. SAR CALCULATION

### *A. Calculation model and conditions*

The SARs in pregnant female models at 20, 26 and 29weeks of pregnancy exposed to vertically polarized EMFs in VHF and UHF bands (30 MHz - 3 GHz) were calculated using the FDTD method. Figure 4 shows the calculation model and conditions. The pregnant female models were assumed to be in free space. The cell size of the calculation region was 2 × 2 × 2 $mm^3$. In addition, the absorbing boundary condition is the perfectly matched layer (PML) (8 layers) [11]. The PML boundaries are set 30 cells from the nearest parts model. The incident waves were assumed to propagate from the anterior to the posterior of a pregnant female model. The incident power density was 1 $mW/cm^2$, which is the reference level for occupational exposure to electromagnetic waves in the very high frequency band [1], [2].

Electromagnetic properties corresponding to the maternal (mother) tissues in the models were obtained from the 4-Cole–Cole analysis reported by Gabriel [12]. The properties corresponding to fetal tissues were also defined on the basis of the empirical equations for predicting the properties of soft tissues [13], because the properties of the fetal (gestational) tissues have not yet been reported.

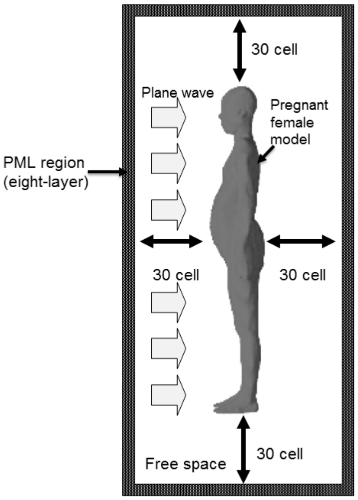


Fig.4. Calculation conditions with a pregnant female model

### *B. SAR characteristics*

The frequency characteristics of the whole-body averaged SARs (WBA-SARs), which is used as the basic restrictions in the RF human safety guidelines [1], [2], of the pregnant female models are shown in Fig. 5. The maximum values of WBA-SARs for each pregnant female model are observed at 80 MHz. The frequencies correspond to the whole-body resonant frequency of the models, where the human-body heights of around 0.4 wavelengths. The result suggests that the WBA-SAR for pregnant female is not significantly affected by the change in body shape and weight with gestation age.

Figure 6 shows the values normalized the fetus averaged SARs by WBA-SARs. These results suggest that the gestation age of pregnant females can affect the fetus-averaged SAR. However, the fetus-averaged SARs for all the gestational models are lower than the WBA-SARs.

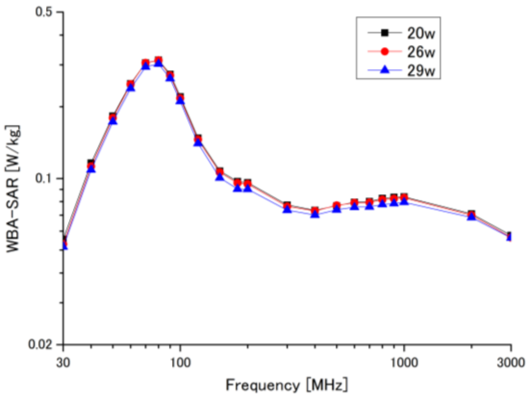


Fig.5. Frequency characteristics for WBA-SARs of pregnant female models.

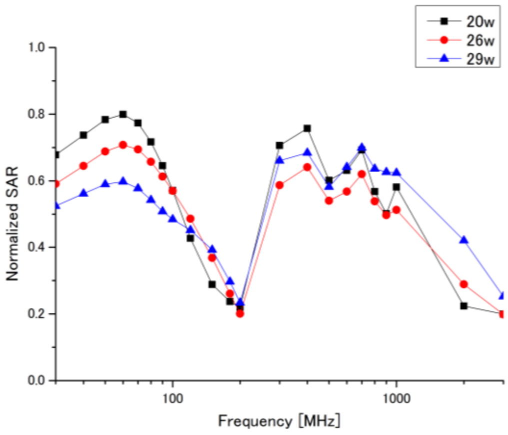


Fig.6. Fetus averaged SAR.

## V. CONCLUSION

In this study, we acquired fetal MRI images with fine-resolution at gestational ages of 20, 26 and 29 weeks from a healthy volunteer and segmented the fetal tissues including gestational tissues into about 20 different tissue types from the acquired images by image processing technique and manual editing. The pregnant female models were also developed by combining the new developed fetal models and the deformed models based on the Japanese female model. The pregnant female models consist of over 70 different tissue types. Therefore, a highly precise simulation for pregnant females and/or the fetus is possible using these whole-body pregnant female models

In this study, the SAR calculations of these pregnant female models exposed to vertically polarized EMFs in VHF and UHF bands were also demonstrated as a preliminary study for numerical dosimetry. We found that the WBA-SAR for pregnant female is not significantly affected by the change in body shape and weight with gestation age, and the fetus-averaged SAR is lower than the WBA-SAR.

## ACKNOWLEDGMENT

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