Japanese Voxel-based Computational Models and Their Applications for Electromagnetic Dosimetry

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Abstract

Recent years have seen development of various high-resolution human computational models using advanced computer performance, and their frequent usage in electromagnetic dosimetry for the human body. The National Institute of Information and Communications Technology (NICT) in Japan used magnetic resonance imaging (MRI) data to develop anatomically realistic whole-body computational models of adult males and females, pregnant females and children of average Japanese body types. In this paper, we detail the Japanese computational models and describe various approaches to modeling and simulation with human computational models.

1 Introduction

The continuing spread of radio-frequency (RF) applications has led to the increasing presence of electromagnetic waves in varying locations. As a result, there is growing concern about the health effects of electromagnetic waves emanating from wireless communication devices. Recently, in order to evaluate RF-EMF safety, fine-resolution anatomically realistic whole-body computational models of various ages and both genders have been developed on the basis of medical imaging data or anatomical photographs. The majority of human computational models have been geared toward Caucasians [1], but their anatomical characteristics are slightly different from Japanese and other Asians. Therefore, to perform detailed evaluation of the electromagnetic dosimetry for these groups, the National Institute of Information and Communications Technology (NICT) has developed several Japanese computational models. In this paper, we introduce these models and explain the technique for applying them for electromagnetic dosimetry.

2 Japanese Computational Models

2.1 Adult Male and Female

NICT has developed anatomical realistic whole-body computational models of Japanese adult males and females in collaboration with Kitasato University, Keio University and Tokyo Metropolitan University, as shown in Fig. 1 [2]. These are the first Asian whole-body anatomical realistic models for electromagnetic dosimetry, and the female model in particular is a global first. The models were constructed on the basis of magnetic resonance imaging (MRI) data on a volunteer 22-year-old Japanese man (height 172.8 cm, weight 65.0 kg) and woman (160.0 cm, 53.0 kg), representative of average Japanese. The models are composed of $2 \times 2 \times 2\ mm^3$ voxels, and are divided into over 50 different tissues and organs. The tissues and organs were identified manually by medical personnel using special identification software developed in-house, in order to correctly classify them from MRI data, and the identified tissues and organs were checked by medical doctors (radiologists).

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2.2 Children

The numerical dosimetry of children is one of the most important issues in EMF safety [3]. NICT previously constructed whole-body child models by non-uniformly rescaling adult models to match the average dimensions of the children's body parts [4] because developing high-resolution computational models is expensive and time-consuming. At the same time, NICT has begun developing MRI-based child models because the anatomical characteristics of scaled child models differ substantially from those of real children. MRI data was acquired for a healthy three- and five-year-old girl and a seven-year-old boy with heights and weights close to the Japanese average values, and NICT recently finished development of the child models. A pediatric radiologist checked the positions and shapes of identified tissues and organs. Figure 3 shows the models we developed, which had a spatial resolution of $1.953 \times 1.953 \times 2\ mm^3$ and are segmented into more than 50 different tissue and organ types.

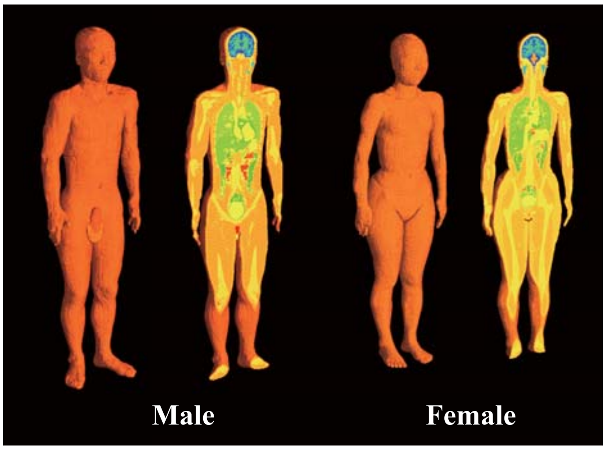

Figure 1: Adult male and female models

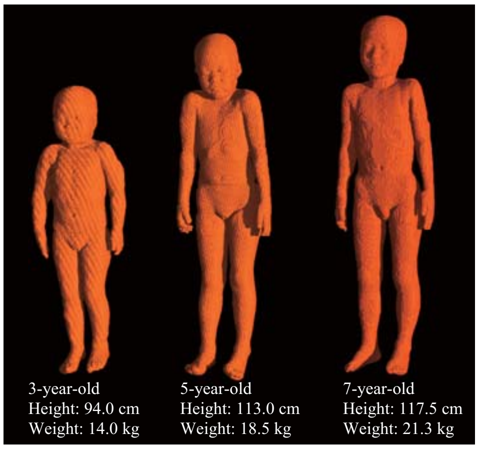

Figure 2: MRI-based child models

2.3 Pregnant Females

As in children, the numerical dosimetry of mother and fetus during pregnancy is also one of the most important issues in EMF safety [3]. In collaboration with Chiba University, NICT has developed a whole-body computational model at 26 weeks' pregnancy [5]. This was developed by combining a model of a fetus including gestational tissue, constructed on the basis of the abdominal MRI data acquired from a healthy female at 26 weeks of pregnancy, and that of a non-pregnant female, deforming the abdomen by applying the free-form deformation (FFD) algorithm. The model is composed of $2 \times 2 \times 2\ mm^3$ voxels and divided into 56 different tissues and organs including gestational tissues (fetal body, fetal brain, fetal eyes, amniotic fluid and placenta). Most recently, we also developed pregnant female models adjusted to the reference values of anatomical characteristics of gestational tissues at various stages of pregnancy [6]. These models are shown in Fig. 4.

3 Applied Techniques for Human Voxel-Based Computational Models

Since the human computational models are generally upright configurations, simulations of actual situations with wireless telecommunication devices (such as cellular phones) and wireless terminals (such as laptop PCs with wireless LAN and WiMAX) are greatly limited. NICT is engaged in a study of posture transformation for human voxel-based computational models, and previously developed two posture transformation techniques; the first applied the FFD algorithm [7], a method that enables smooth posture transformation

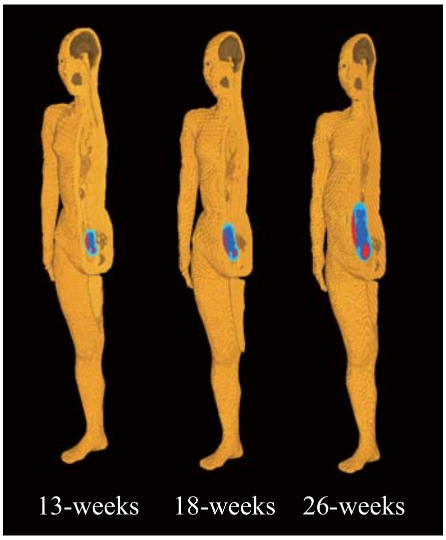

Figure 3: Pregnant female models

while keeping the continuity and masses of the model's internal tissues and organs. This technique, however, was disadvantageous in that the structural quality of the tissues and organs in the postured models greatly depended on allocating and numbering the control lattice points of FFD. To relieve this issue, we proposed another technique in which the polygon mesh data of the model are generated based on the body surface contour of the voxel-based models, and the meshes are deformed using a skeleton animation tool in a commercial three-dimensional graphic software package. Arbitrary voxel-based posture models are constructed by utilizing volume morphing technique called as "volume refilling" to the deformed mesh data [8] (see Fig. 5).

The human computational models developed by NICT have high spatial resolution (about 2 mm) and enable us to evaluate exposure to high-frequency electromagnetic radiation up to about 3 GHz. We have to use higher-resolution models to be able to evaluate exposure to electromagnetic fields of higher frequencies since wireless communication devices will be used at frequencies above 3 GHz in the near future. NICT has developed a technique for creating arbitrary higher-resolution models by smoothing the irregularities between tissue boundaries, as shown in Fig. 6 [9].

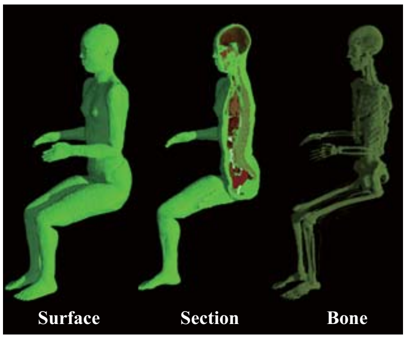

Figure 4: Sitting female model with the volume refilling technique

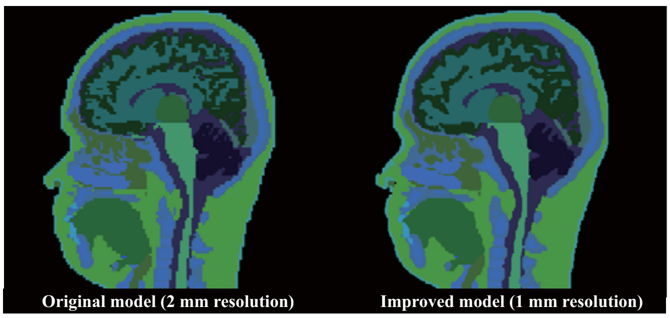

Figure 5: Example of arbitrary resolution voxel-based model

4 Conclusion

This paper introduced the characteristics of Japanese computational voxel models of adults, children and pregnant females for electromagnetic dosimetry. The models consist of approximately 2 mm^3 voxels and are segmented into more than 50 different tissues and organs. These are optimal for electromagnetic dosimetry for Asians, who account for about 58% of the world 's population, and will offer high-precision simulation. We also described approaches to modeling and simulation with a human computational model. The advanced models constructed by our applied technique will be able to provide electromagnetic dosimetry for realistic exposure scenarios.

5 References

1. X.G. Xu and K.F. Eckerman, "A Handbook of Anatomical Models for Radiation Dosimetry," Taylor Francis, 2009.

2. T. Nagaoka, S. Watanabe, K. Sakurai, E. Kunieda, S. Watanabe, M. Taki, and Y. Yamanaka, "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.,* 2004, pp. 1-15.

3. WHO, *Research Agenda for Radio Frequency Fields,* 2006.

4. T. Nagaoka, E. Kunieda, and S. Watanabe, "Proportion-corrected scaled voxel models for Japanese children and their application to the numerical dosimetry of specific absorption rate for frequencies from 30 MHz to 3 GHz," *Phys. Med. Biol.,* 2008, pp. 6695-6711.

5. T. Nagaoka, T. Togashi, K. Saito, M. Takahashi, K. Ito, and S. Watanabe, "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., 2007, pp. 6731-6745.

6. T. Nagaoka, K. Saito, M. Takahashi, K. Ito, and S. Watanabe "Anatomically realistic reference models of pregnant women for gestation ages of 13, 18, and 26 weeks," *Proc. 30th Ann. Intl. Conf. of the IEEE EMBS,* Vancouver, British Colombia, Canada 2008, pp. 2817-2820.

7. T.Nagaoka and S. Watanabe, "Postured voxel based human models for electromagnetic dosimetry," *Phys. Med. Biol.,* 2008, pp. 7047-7061.

8. T. Nagaoka and S. Watanabe, "Voxel-based variable posture models of human anatomy," *Proceedings of the IEEE,* 2009, pp.2015-2025.

9. T. Nagaoka and S. Watanabe, "Technique using implicit fairing and specific absorption rates to improve spatial resolution of whole-body human voxel models exposed to plane waves in GHz bands," *URSI general assembly,* Chicago, IL, August, 2008.