Development of Korean Male Body Model for Computational Dosimetry

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ABSTRACT—The dimensions of the human body vary by age, sex, and race. The internal structure and outer dimensions of a body exposed to an electromagnetic field is important for accurate dosimetry. The average physical size of Korean adult males between the ages 18 to 24 was investigated, and a male volunteer was selected whose physical condition is within the physical standards, ± 5%. Magnetic resonance images and partially computerized tomography images of the volunteer were acquired. The intervals between the transverse images were 1 mm for the head and 3 mm for the rest of the body. About 30 different tissues were manually classified by an anatomist on the raw images, and the segmented images were implemented in the form of a text file appropriate for numerical formulation.

Keywords—Anatomical human model, MR image, CT image, voxel, dosimetry, numerical analysis.

I. Introduction

The recent and rapid development of computer resources has enabled the internal dosimetry of an anatomical human body in voxel-based format using the finite-difference time-domain (FDTD) technique. Anatomical human models enable simulation of a real environment exposed to an electromagnetic field and are essential subjects for deducing a standard human model and a technique for better dosimetry [1], [2].

Available human models are not Asian-based, and some body dimensions of such models widely differ from the average Korean physique [3], [4]. Therefore, a new voxel model is needed to consider accurate dosimetry in a Korean human body for electromagnetic field exposures.

In this letter, the development process of a voxel-based human body model and its results are described. A volunteer was selected based on the average physique of Korean males, and his body was imaged from the crown of the head to the tip of his toes using magnetic resonance (MR) imaging and computerized tomography (CT) scans. For these two types of images, an MR machine (GE Signa Horizon 1.5 Tesla MRI System) and CT machine (GE High Speed Advantage) were used. The CT scans were performed only in a partial head region for better identification of bone, fibrous tissue, and interior air. Based on these images, a three-dimensional anatomical data set suitable for numerical analysis in a rectangular grid, such as the FDTD technique, was implemented.

II. Physical Condition of Volunteer, Acquirement of Diagnostic Images, and Segmentation of Tissues

The selected volunteer was a healthy male, 21 years of age. His height and weight were 176.0 cm and 67.0 kg. The average physical size of Korean males in the age range of 18 to 24 represents the mean average sizes for 118 parts of the human body. The physical data used to select the volunteer was extracted from results of the average national physique surveyed in 1997. Table 1 compares the representative physical items between the measurements of the volunteer and the national averages. It shows that all of the volunteer's measurements exist in the range of average, ± 5%.

For a better differentiation between tissues with short scanning time, various conditions of MR imaging parameters were tested. Finally, the inversion recovery fast gradient recalled image (IRFGRE) technique was selected, which offers

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Table 1. Comparison of Korean standard and volunteer's physique.

Anatomy	Standard	Volunteer	Anatomy	Standard	Volunteer
Height (cm)	171.4	176.0	Chest circumference (cm)	86.8	88.8
Weight (kg)	63.9	67.0	Waist circumference (cm)	73.6	76.9
Head breadth (cm)	15.8	16.0	Hip circumference (cm)	91.5	93.8
Head length (cm)	18.1	18.7	Thigh circumference (cm)	53.6	53.4
Chin-vertex length (cm)	23.2	22.9	Sitting height (cm)	81.0	81.3
Head circumference (cm)	56.3	56.9	Waist height (cm)	103.4	103.8

Table 2. MR parameters.

Parameter / Region	Head	Body
Sequence	3D IRGFRE	T1 conventional spin echo
TR/TE	9/1.8 ms	800/14 ms
FOV	26 cm	48 cm
Matrix	256×256	256×256
Slice thickness	1 mm	3 mm

an excellent contrast of cartilaginous tissue and reduces the time needed for the total images by adding a 500 ms inversion pulse to a gradient echo sequence and maximizing the T1 weighted image. This technique enabled the imaging sequence period to within 15 minutes for the head part and minimized artifacts due to motion of the volunteer.

Images for the two parts of the volunteer were taken, separately. The first part includes the head and neck with a spatial resolution of $1 \times 1 \times 1$ mm^3, and the second part is the whole body from shoulder to toe with a resolution of $3 \times 3 \times 3$ mm^3.

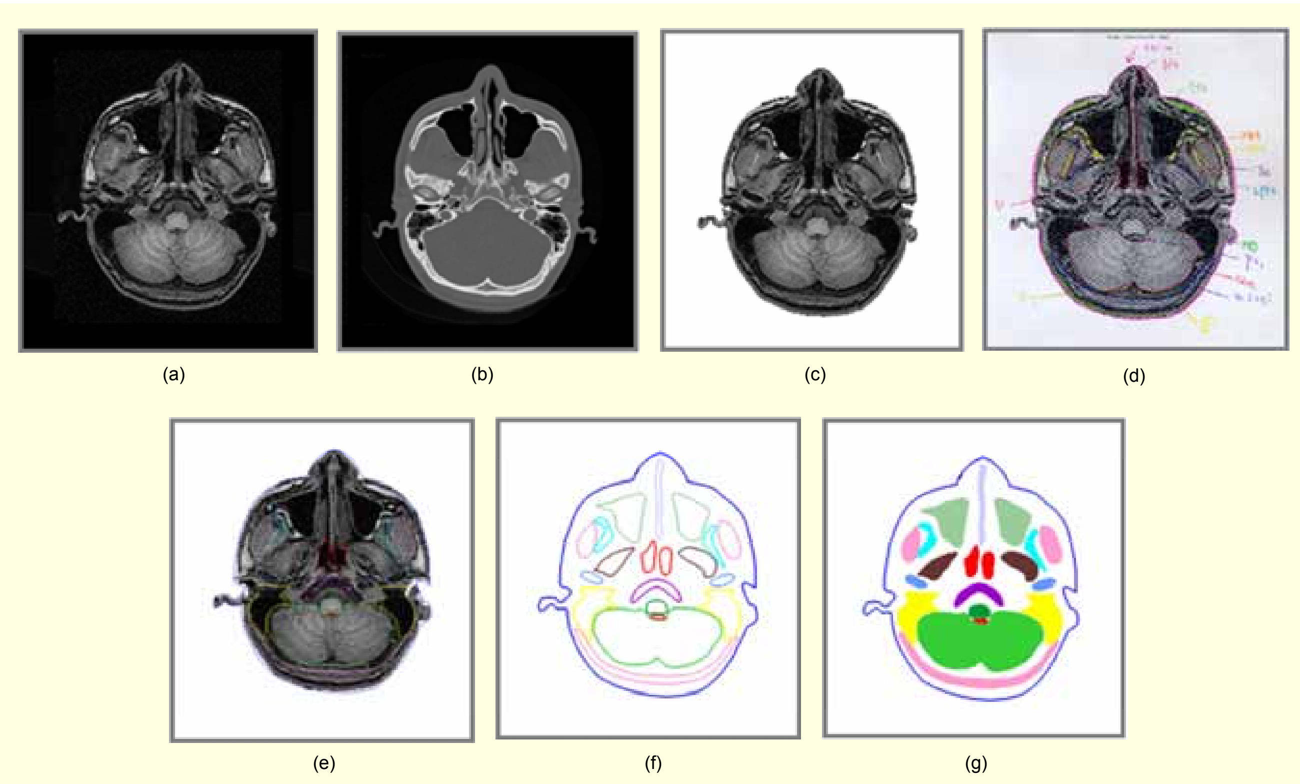

Fig. 1. Segmentation process on the horizontal plane through the nose; (a) original MR image, (b) original CT image, (c) background-removed MR image, (d) manual classification on paper, (e) classification on the MR image with color lines using Corel Draw; (f) image (e) with MR background removed, and (g) color-filled image from (f).

Table 3. The voxels of the tissues of head and whole body models.

Tissues	ID	Head	Whole body
Interior air	0		
Bladder	1	-	3,545
Blood	2	16,303	50,255
Bone cortical	4	807,906	179,746
Bone marrow	6	-	88,152
Cartilage	8	6,405	36
Cerebellum	9	190,395	7,344
Cerebrospinal fluid	10	239,105	13,069
Colon (large intestine)	11	-	18,940
Eye	14	14,121	550
Fat	15	160,591	463,899
Grey matter	19	1,149,313	43,919
Heart	20	-	22,823
Kidney	21	-	14,055
Lens	23	249	6
Liver	24	-	60,747
Lung	26	-	120,942
Muscle (parallel fiber)	27	1,069,655	-
Muscle (transverse fiber)	28	192,339	1,286,781
Nerve (spinal cord)	29	94,319	4,864
Skin (dry)	31	210,205	-
Skin (wet)	32	723,137	341,472
Small intestine	33	-	52,525
Spleen	34	-	8,992
Stomach, esophagus, duodenum	35	-	25,133
Tendon	36	-	7,625
Testis, prostate	37	-	4,422
Thyroid, thymus	38	2,579	-
Tongue	39	73,505	2,886
Trachea	40	2,621	3,047
Total voxels		4,952,817	2,825,775
Total volume (cm^3)		4,953	76,296

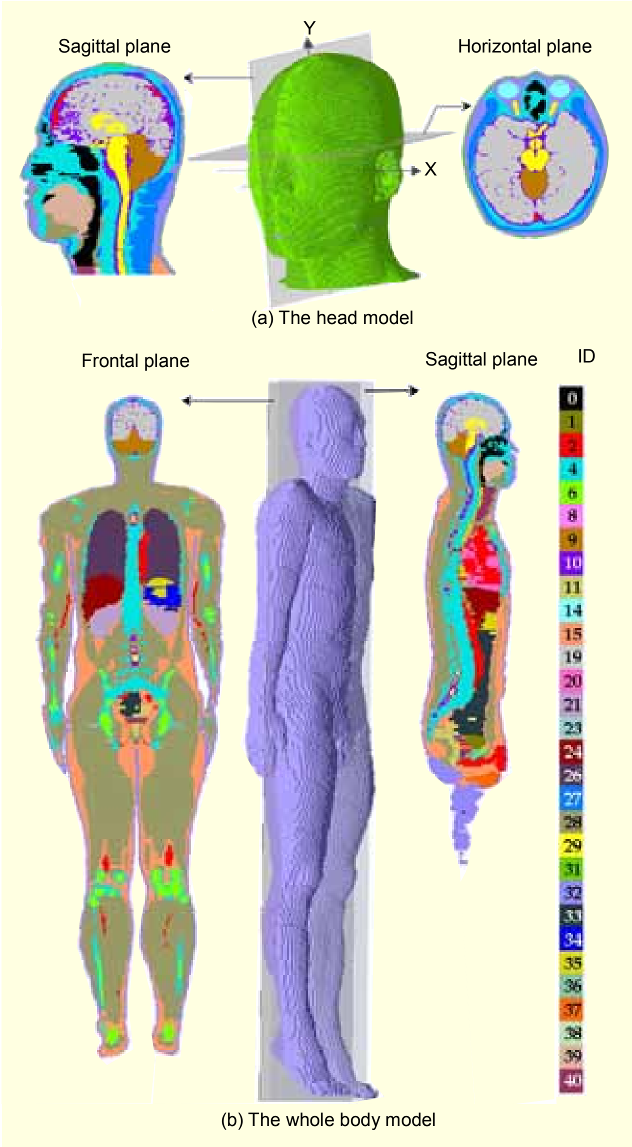

Fig. 2. The Korean adult model.

The images for the heart region were taken for one period of a heart beat through an adhered EKG lead since heart beating and respiratory motion cause an acute distortion of the images. The MR parameters for the head and body are compared in Table 2.

The MR images had been first classified into 64 and 30 tissues for the head and body parts, respectively. However, in order to make a suitable voxel model for use in electromagnetic dosimetry, some kinds of tissues were replaced with those for which the dielectric properties are generally known. Finally their own index numbers for 29 tissues in Table 3 were endowed in a text file.

Figure 1 shows the serial images according to the work process on a cross section of the head. Figures 1(a) and 1(b) represent the original MR and CT images. First, we removed the background from the MR image as shown in Fig. 1(c). Next, using the CT image as a reference, the tissue and organ outlines were drawn manually on the printed background-removed MR image with color pencils by an anatomist, the result of which is shown in Fig. 1(d). Then, we reproduced the outlines onto a computerized version of the MR image as shown in Fig. 1(e) using Corel Draw 6.0. By removing the underlying MR image as in Fig. 1(f) and shading in the closed color lines as in Fig. 1(g), we could save the final image in bitmap form.

Table 3 represents the classified tissue list and the number of voxels of each tissue. The head part and whole body have resolutions of 1 × 1 × 1 mm^3 and 3 × 3 × 3 mm^3, respectively. At the lowest line of the table, the total number of voxels and the volume of each model are shown.

III. Data Identification

Implemented voxel models can be identified through the developed software, which enables one to view the model two- or three-dimensionally and identify the tissue type at an arbitrary spatial point. Figure 2 shows the three-dimensional and cross- sectional views of the head and whole body models, respectively. The color bar indicates the tissue ID numbers of Table 3. The black color in Fig. 2 represents the interior air of the body. The green color of the head model represents the dry skin. We can see both the dry and wet skins on the cross sectional view of the head model. However, only one type of skin was obtained for the whole body model due to the bigger voxel size than that of the head model.

IV. Conclusions

We have developed a set of voxel-based human models whose dimensions are very close to the standard physique of a Korean male adult. The head model has been applied to some numerical simulations of electromagnetic absorption in the head by radiation of a mobile phone [5], [6]. These models can help for the determination of an electromagnetic dose for human exposure to various electrical devices, a diagnostic system design for tumor detection, visual image processing for anatomical human models, and so on. Furthermore, this set of models made from a Korean volunteer can be applied to study the effects of racial difference in physique on electromagnetic absorption.

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