Development of 7-Year-Old Korean Child Model for Computational Dosimetry

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ABSTRACT—A whole-body voxel model of a 7-year-old male volunteer was developed from 384 axial magnetic resonance images (MRIs). The MRIs were acquired with intervals of 3 mm for the entire body in a body coil. In order to reduce the MRI acquisition time for the child, the repetition and echo times under T1 weighted image were chosen to be 566 ms and 8 ms, respectively. The MRIs were classified according to 30 types of tissues with known electrical parameters. The developed voxel model was adjusted to the physical average of 7-year-old Korean boys. The body weight of the adjusted model, calculated with the mass tissue densities, is within a 6% difference from the 50th percentile weight.

Keywords—Whole-body child voxel model, magnetic resonance image, electromagnetic exposure, dosimetry.

I. Introduction

The recently released research agenda of the WHO international electromagnetic field (EMF) project recommends the development of child models for EMF dosimetry [1]. The shape of a child's body varies with age, and it can be an important factor that affects the absorption results in the body from EMF exposure. For example, the head accounts for about a quarter of the body length in neonates, but the corresponding proportion is only around 10% in adults. Growth of the head primarily takes place during the first ten years of life, and the rest of the body grows rapidly during puberty, causing the head-to-body ratio to decrease [2], [3].

For these reasons, although many adult models have been developed based on medical imaging technology, they cannot be used directly for the dosimetry of a child and should be altered to conform to a child's physical dimensions. Therefore, the way to remain most faithful to a child's anatomy is to develop a voxel model based on a child's medical images. We chose a 7-year-old male child as a volunteer since many children at that age begin to be exposed to radio frequency (RF) devices, such as mobile phones, laptop computers equipped with wireless modems, and so on.

The process of developing a voxel-based child body model is very similar to that used to develop an adult one [4], but we did not obtain the child volunteer's CT images. Instead, based on the images from the crown of the head to the feet obtained using a magnetic resonance imaging (MRI) scan, a three-dimensional anatomical data set was developed, suitable for numerical analysis in a rectangular grid, as in the finite-difference time-domain technique. The initial voxel model was adjusted to the 50th percentile body sizes of 7-year-old Korean males since it had some discrepancies from the average physique at that age.

II. Acquisition of Diagnostic Images and Segmentation of Tissues

For the medical images of the volunteer, an MRI machine (GE Signa Horizon 1.5 Tesla MRI System) was used. A total of 384 axial MRIs were acquired at 3 mm intervals and 1 mm^2 pixel size for each cross-section for the entire body within a body coil. The images of the heart region were taken during each period of a heart beat through an adhered electrocardiogram lead since both cardiac and respiratory motion cause severe distortion

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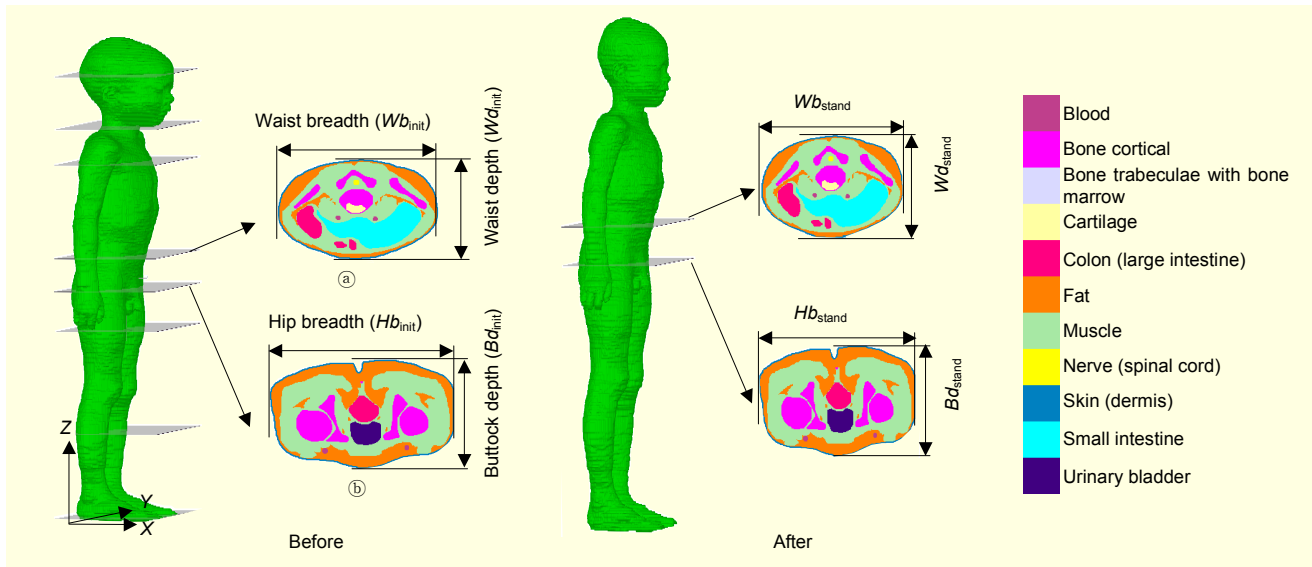
Fig. 1. Exterior dimension adjustment of the child model.

of the images. To reduce the required MRI time for the child, the repetition and echo times under a T1 weighted image were chosen to be 566 ms and 8 ms, respectively.

Thirty types of tissues or organs were classified, whose permittivities and conductivities are known based on Gabriel's research results [5]. The epidermis and dermis could not be distinguished from each other and were simply defined as skin (dermis) since it is spatially dominant. The brainstem was classified independently so that white and grey matter could be intermixed.

On the MRIs, the selected tissues were outlined automatically using the magic wand tool of Adobe Photoshop. When automatic outlining was not possible, semiautomatic outlining was done using the quick selection tool. It was also helpful to use a Wacom™ tablet pen instead of a computer mouse for outlining. Eventually, the segmented images, in which the outlines of the structures were filled with different colors, were saved as 8-bit color TIFF files in Adobe Photoshop as shown in Fig. 1. The segmented images were converted into a text voxel file [6].

III. Standardization of the Body Dimensions

The selected volunteer was a healthy male, 7 years of age. The detailed body dimensions were not measured, and the developed model showed some discrepancies from the standard physical sizes of that age. Since body dimensions can affect the dosimetric results for an EM exposure, the initial voxel model was adjusted to the standard size to obtain representative data for the subject's age.

The 2004 national survey provided only physical exterior dimensions of both genders at various ages [3]. The 50th percentile values of sixteen anthropometric parameters for 7-year-old Korean males are shown in Table 1. Twelve of them could be evaluated on the corresponding eight cross-sections shown on the left side of Fig. 1 and adjusted to closely match these standard dimensions, keeping the original pixel size of 1 mm^2. The dimensions of the other cross sections between adjacent ones were linearly adjusted between the scaling rates for the two cross-sections; for instance, the breadths of the cross-sections between ⓐ and ⓑ are determined from the rates Wb_{stand}/Wb_{init} and Hb_{stand}/Hb_{init}, where the subscripts "init" and

Table 1. Comparison of the physiques of the Korean standard (the 50th percentile value) for 7-year-old males and adjusted voxel model.

Anatomy	Standard (mm)	Adjusted (mm)
Head height	210	210
Head length	170	171
Head breadth	149	150
Face length	95	93
Neck circumference	270	272
Chest breadth	202	201
Chest depth	140	141
Waist breadth	194	195
Waist depth	143	142
Hip breadth	218	216
Buttock depth	154	153
Thigh circumference	375	374
Calf circumference	255	254
Foot length	190	190
Waist height	740	741
Stature	1,224	1,224

Table 2. Tissue types and weights of the adjusted child voxel model.

ID	Tissue/Organ	Mass density (kg/m^3)	Weight (kg)
1	Urinary bladder	1,030	0.0680
2	Blood	1,058	0.1047
4	Bone cortical	1,990	3.8936
6	Bone trabeculae with bone marrow	1,040	0.3143
8	Cartilage	1,097	0.0828
9	Cerebellum	1,038	0.1747
10	Cerebrospinal fluid	1,007	0.0697
11	Colon (large intestine)	1,043	0.3265
14	Eye (Sclera)	1,026	0.0049
15	Fat	916	4.3040
17	Gallbladder	1,030	0.0024
19	Grey matter	1,038	0.8233
20	Heart	1,030	0.2526
21	Kidney	1,050	0.1435
22	Lens cortex	1,053	0.0002
24	Liver	1,030	0.7044
26	Lung	1,050	0.7894
27	Muscle	1,047	9.4104
29	Nerve (spinal cord)	1,038	0.0307
32	Skin (dermis)	1,125	1.9661
33	Small intestine	1,043	0.7149
34	Spleen	1,054	0.0806
35	Stomach, esophagus	1,050	0.2315
37	Testis	1,044	0.0079
38	Thyroid	1,050	0.0011
39	Tongue	1,050	0.0218
40	Trachea	1,040	0.0049
42	Vitreous body	1,009	0.0090
43	White matter	1,038	0.4087
44	Brainstem	1,038	0.0309
	Whole body		25.50

"stand" mean the dimension of the initial voxel model and the corresponding standard value, respectively.

The rest of the parameters for head height, face length, waist height, and stature are dimensions on the *z*-axis. These were also adjusted to standard dimensions, keeping the same voxel size. Figure 1 shows the two voxel models before and after adjustment.

The body dimensions of the adjusted model are compared with the 50th percentile data (the standard physique) in Table 1, and the differences between them are within $\pm 2\%$. The weight of each tissue or organ and whole body weight were calculated using the mass densities [7] in Table 2. The calculated body weight of the modified model was 25.5 kg, which is about a 6% deviation from the standard weight (24.1 kg) of 7-year-old Korean males.

IV. Conclusion

There are not many child models available based on the medical images of real children, although the WHO puts an emphasis on child dosimetry. For the computational EMF dosimetry of children, we have developed a child voxel model based on a 7-year-old volunteer's MRIs. Also, sixteen body sizes of the initial model were adjusted to the standard physique to obtain the representative dosimetry results for a normal male at that age.

Future dosimetry will require more flexible and dynamic human body models. Recently, a pediatric series of voxel models was created at the University of Florida for similar purposes. Non-uniform rational B-spline surfaces were adopted for much more sophisticated voxel modeling [8].

The child model in this study can be widely applied to computational dosimetry even though it does not allow for a perfect description of each tissue or organ. However, the voxel-based model needs to import new technologies such as the above technique or a computer aided design in order to include more detailed and accurate tissue types and smoother surfaces of organs, or to expand its application frequency into a much higher frequency band.

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