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Construction of Tomographic Head Model Using Sectioned Photographic Images of Cadaver

Choonsik Lee and Jaiki Lee
Innovative Technology Center for Radiation Safety, Hanyang University, Seoul, Korea

Jinseo Park and Minsuk Chung
Department of Anatomy, Ajou University School of Medicine, Suwon, Korea

ABSTRACT

Tomographic models are currently the most complete, developed and realistic models of the human anatomy. They have been used to estimate organ doses for diagnostic radiation examination and radiotherapy treatment planning, and radiation protection. The quality of original anatomic images is a key factor to build a quality tomographic model. Computed tomography (CT) and magnetic resonance imaging (MRI) scan, from which most of current tomographic models are constructed, have their inherent shortcomings. In this study, a tomographic model of Korean adult male head was constructed by using serially sectioned photographs of cadaver. The cadaver was embedded, frozen, serially sectioned and photographed by high resolution digital camera at 0.2 mm interval. The contours of organs and tissues in photographs were segmented by several trained anatomists. The 120 segmented images of head at 2mm interval were converted into binary files and ported into Monte Carlo code to perform an example calculation of organ dose. Whole body tomographic model will be constructed by using the procedure developed in this study.

1. INTRODUCTION

Computational models of human anatomy are the mathematical representation of the external body and internal organs and tissues. They have been widely used to calculate organ doses in diagnostic radiation examination, radiotherapy treatment planning and radiation protection purpose being ported into Monte Carlo radiation transport codes. The first heterogeneous computational model, known as Medical Internal Radiation Dose (MIRD) phantom, was designed at Oak Ridge National Laboratory (ORNL) for the adult male [1]. The model described the shapes of human body and organs by the combinations of the mathematical equations describing planes, cylinder, cone, ellipsoid, and sphere. Several modified or extended versions of stylized (or called MIRD-type) model have been developed thereafter, and utilized in computations of dosimetric quantities [2-5].

Although the stylized models extensively contribute to computational radiation dosimetry, there are potential deviations in the resulting dosimetric quantities from real human anatomy. This is particularly the case for those organs or tissues having complicated geometries difficult to represent by using simple mathematical equations. As a substitute for stylized model, tomographic (or called voxel) models have been developed, which can very precisely describe both the shape of the body and of internal organs. They provide currently the most realistic representation of human anatomy for radiation dosimetry calculation. The tomographic models were first introduced by Gibbs *et al.* followed by Williams *et al.*, and various tomographic models were constructed by several authors during the last decade [6-15].

The quality of the original anatomic images is a key factor to build a quality tomographic model. Computed tomography (CT) and magnetic resonance imaging (MRI) scan, from which most of current tomographic models are constructed, have their inherent shortcomings in image quality. Whole body CT scanning gives a considerable radiation dose to subject, whereas MR raises no consideration of radiation. However, MR scanning takes too long time to get a clear image of moving organs. General purposed CT scanning without contrast agent also offers vague images of digestive organs.

National Library of Medicine's (NLM) Visible Human Project (VHP) became available to build the most detailed digital image library of the human anatomy [16]. Visible Photographic Man (VIP-Man), the world first tomographic model based on color photographs, was developed using the color photographic images for radiation transport studies [11]. However, it is difficult to adopt it for the oriental racial group because the external shape and organ size of VIP-Man not only from oriental population but also from Caucasian reference man recommended by ICRP [17]. In this study, a tomographic model of Korean adult male head, which was a preliminary model to whole body tomographic model, was constructed by using serially sectioned photographs of Korean male cadaver.

2. MATERIALS AND METHODS

2.1. Sectioned photographs of cadaver

Several sets of whole body CT/MR/color photographs were obtained by the Visible Korean Human project of Ajou university school of medicine to build the most detailed digital image library of the human anatomy [18]. A Korean male who was 33-years-old, and had average body size, the height of 1,718 mm and the weight of 55 kg, was donated. There were few pathological findings (leukemia). The donated cadaver of Korean male was embedded, frozen, serially sectioned and photographed by high resolution digital camera at 0.2 mm interval. Figure 1 shows the axial tomographic images of the three modalities, MR, CT and color photographs of Visible Korean Human's head at the level of eye lens.

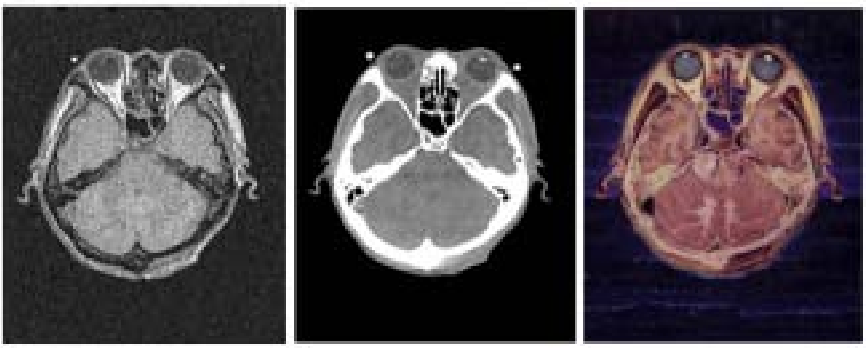

Fig. 1. MR (left), CT (center) and anatomical photographs (right) of Visible Korean Human

2.2. Construction of tomographic head model

The segmented images were made from anatomic photographs by Ajou university research group to be used in making three-dimensional images of detailed human anatomy. The contours of several organs and tissues in photographs were segmented by several trained anatomists using semiautomatic segmentation software, Photoshop6.0. Since the purpose of the segmentation differed from that of this study, the eye balls and lenses, which have a dosimetric significance, were additionally segmented by manual drawing. Figure 2 shows the examples of the original sectioned photograph and segmented image at the level of eye lens. Lens, eye ball, skull, cerebrum and cerebellum were segmented and labeled with the corresponding index number. The commercial image processing software, Photoshop7.0^{TM} (Adobe Systems, Inc., San Jose, CA) and graphic digitizer PL-400^{TM} (WACOM Co., Ltd, Japan) were utilized for manual segmentation.

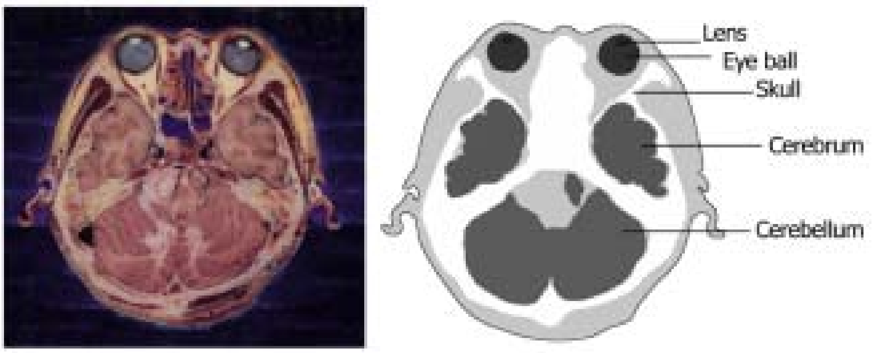

Fig. 2. Original sectioned photograph (left) and segmented image (right) at the level of lens.

The 120 segmented images of head at 2mm interval were converted into binary files using Photoshop7.0. The software has an inherent function to convert the segmented image in JPEG format into binary file in RAW format. The RAW-formatted files were integrated into one binary file, and converted into ASCII file, which was ported into the input deck of Monte Carlo code by using the in-house code *Voxelmaker2.0*.

2.3. Example Monte Carlo calculation

Illustrative calculations of brain and lens absorbed doses were made using the Monte Carlo code MCNPX2.4 for broad parallel beam of photons from 0.015 MeV to 10 MeV irradiating from antero-posterior (AP) and postero-anterior (PA) [19]. Since MCNPX2.4 does not provide a built-in routine for managing voxel geometries, the *Repeated Structure* algorithm was utilized to describe the geometry of the tomographic model. The energy deposition tally, **F6* was used with the unit conversion option to acquire the mean organ absorbed dose. A personal computer equipped with a 2.5 GHz Intel processor and 512 MB RAM operated by Microsoft Windows XP was used for computation. The average tissue compositions and densities recommended in ICRU 44 were used to describe the tissues [20].

3. RESULTS AND DISCUSSIONS

3.1. Korean tomographic head model

Tomographic head model of Korean adult male, named KPHEAD (Korean Photographic Head), was constructed by segmenting 7 individual critical organs and tissues from anatomic photographs. The data array of 300×198×120 voxels required storage of 15.4 MB and the single voxel size was 2×2×2 mm^3. Figure 3 shows the 3-dimensional views of the external shape of KPHEAD and its skull rendered by in-house code *Voxelviewer2.0*.

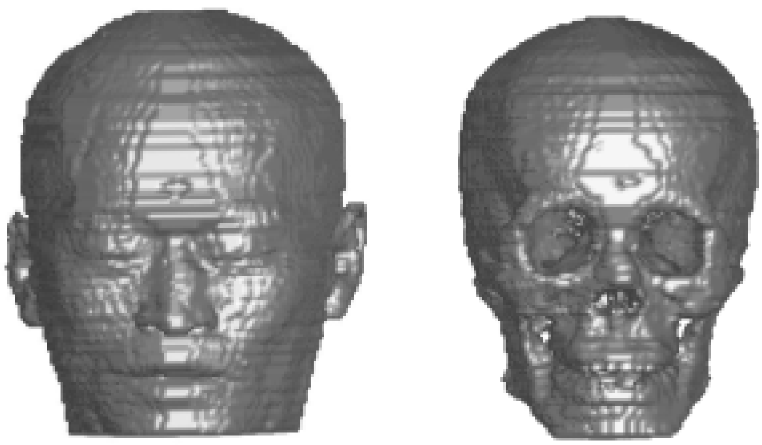

Fig.3. Three-dimensional views of outermost contour (left) and skull (right) of Korean tomographic head model.

3.2. Example calculation

Example calculations of organ absorbed doses for eye lens and brain were made using the Monte Carlo code MCNPX2.4 for broad parallel beam of photons from 0.015 MeV to 10 MeV irradiating from AP and PA. Figure 4 depicted the representative organ dose equivalent per unit air kerma (Gy/Gy) for brain calculated by KPHEAD and those of ICRP74 in AP and PA geometries [21]. Since dose conversion coefficients for brain are omitted in ICRP74, those were calculated by using MIRD5 human model. Dose conversion coefficients in ICRP74 are based on the result of calculating using MIRD-type human models. There was little difference between ICRP74 and KPHEAD. It means the brain model of MIRD-type models realistically represent that of real human. Dose conversion coefficients for eye lens from KPHEAD and those of ICRP74 were presented in figure 5. There was a significant difference at low and high photon energy, whereas little difference in PA geometry was shown. Lens of KPHEAD received higher dose than that of ICRP74 at high energy over 0.8 MeV. In case of lower energy than 0.05 MeV, lens of KPHEAD received lower dose than that of ICRP74. That was caused by the difference of lens model between the two human models.

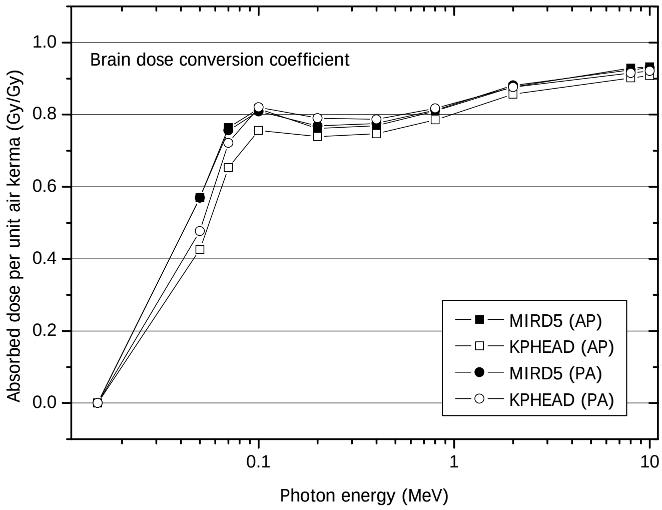

Fig. 4. Dose conversion coefficients for brain from KPHEAD and MIRD5 human model for broad parallel beam of photons from 0.015 MeV to 10 MeV in AP and PA irradiation geometries.

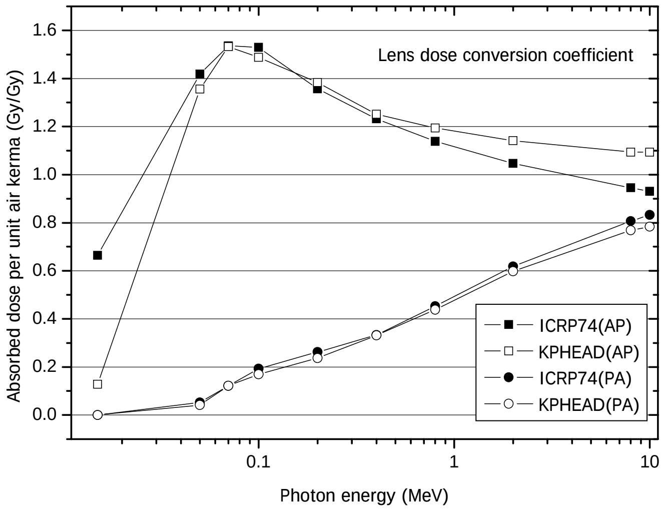

Fig. 5. Dose conversion coefficients for eye lens from KPHEAD and ICRP74 for broad parallel beam of photons from 0.015 MeV to 10 MeV in AP and PA irradiation geometries.

4. CONCLUSIONS

Tomographic head model of Korean adult male, named KPHEAD (Korean Photographic Head), was constructed by segmenting 7 individual critical organs and tissues from anatomic photographs. Several sets of whole body CT/MR/color photographs were obtained by the Visible Korean Human project of Ajou university school of medicine to build the most detailed digital image library of the human anatomy. The donated Korean male was 33-years-old, and had average body size, the height of 1,718 mm and the weight of 55 kg, who had few pathological findings (leukemia). The donated cadaver of Korean male was embedded, frozen, serially sectioned and photographed by high resolution digital camera at 0.2 mm interval. The constructed data array of 300×198×120 voxels required storage of 15.4 MB and the single voxel size was 2×2×2 mm^3. Example calculation of organ dose for idealized gamma radiation field showed the utility of KPHEAD for radiation protection calculation. Whole body tomographic model will be constructed by using the procedure developed in this study. The model will be the world second whole body tomographic model, following VIP-Man mentioned above, and maybe more adoptable for oriental and western population than VIP-Man.

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