Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 20-21, 2022

Body-size-dependent pediatric phantom library constructed from ICRP pediatric mesh-type reference computational phantoms

Suhyeon Kim[a], Bangho Shin[a], Chansoo Choi[b], Hyeonil Kim[a], Haegin Han[a], Sungho Moon[a], Gahee Son[a], Beom Sun Chung[c], Chan Hyeong Kim[a*]

[a]*Department of Nuclear Engineering, Hanyang University, Seoul, Korea*
[b]*J Crayton Pruitt Family Department of Biomedical Engineering, University of Florida, Gainesville, FL, USA*
[c]*Department of Anatomy, Yonsei University Wonju College of Medicine, Wonju, Korea*
[*]*Corresponding author: chkim@hanyang.ac.kr*

1. Introduction

The International Commission on Radiological Protection (ICRP) developed the mesh-type reference computational phantoms (MRCPs) for adult male and female through ICRP *Publication 145*, which are counterparts of the voxel-type reference computational phantoms (VRCPs) in ICRP *Publication 110*. Following the development of the adult MRCPs, the ICRP recently completed the development of the pediatric MRCPs (i.e., newborn, 1-, 5-, 10-, and 15-year-old male and female) by converting the pediatric VRCPs in ICRP *Publication 143*. One of the main advantages of the MRCPs over the VRCPs is high deformability, which enables the MRCPs into different body sizes or postures [1]. By deforming the adult MRCPs, the body-size-dependent phantom library, which consists of 212 phantoms (108 for males and 104 for females), was developed for individualized dosimetry (e.g., medical image optimization) [2].

Recently, the number of CT examinations for children has dramatically increased [3]. Considering the fact that children are more susceptible to radiation-induced risks than adults (e.g., leukemia and various cancers) due to their high radiation sensitivity and long life expectancy, it is necessary to accurately estimate doses for children. Therefore, in the present study, the body-size-dependent phantom library covering wide range of body sizes (i.e., height and weight) for infants, children, and adolescents (i.e., newborn to 19 years) was developed by deforming the pediatric MRCPs. To see the impact of the body size on dose calculations for children, the doses to the stomach, breast, and brain were calculated by using the phantoms at different weights for external exposure to photons.

2. Materials and Methods

The body-size-dependent pediatric phantom library was developed in three steps: construction of (1) height–weight grids and secondary anthropometric parameters, (2) grid-center and anchor phantoms, and (3) phantom library by using the in-house C++ program.

The target height–weight grids and secondary anthropometric parameters were first constructed for newborn and 1–19 years. The height and weight for 403 grid bins (10 and 11 for newborn males and females; 217 and 192 for 1–19 years males and females) were determined by using the data given in Huvanandana *et al.* [4] and National Health and Nutrition Examination Survey (NHANES) IV [5]. The secondary anthropometric parameters (i.e., newborn: head and abdominal circumference; 1–19 years: head height, breadth, and length; sitting height; and upper arm, waist, hip, thigh, and calf circumference) were considered by using the data given in various dataset and scientific literatures [4–10]. Detailed information on the determination of grid bin and secondary anthropometric parameters can be found in Ha *et al.* [11].

The next step is the construction of grid-center and anchor phantoms for 1–19 years to be used as basis models to construct the pediatric phantom library. These phantoms were constructed to realistically represent the body shape of automatically generated phantoms, which have wide range of height and weight [2]. Note that grid-center and anchor phantoms are not required for newborn, because the newborn has narrow range of height and weight grids. Eight grid-center phantoms were manually constructed by deforming the pediatric MRCPs. Then, a total of 56 anchor phantoms having the same lean body mass (LBM) and different body fat percentages were constructed by deforming the grid-center phantoms. Detailed information on grid-center and anchor phantoms can be found in Choi *et al.* [2].

Finally, the body-size-dependent pediatric phantom for each grid bin was automatically constructed by using the in-house C++ program. For the newborn phantom library, in-house C++ code was developed to directly scale the newborn MRCPs in XYZ directions. For the phantom from 1 to 19 years, the C++ program used to construct the adult phantom library [2] was updated and used to automatically scale the phantoms to match the target height, weight, and secondary anthropometric parameters. In addition, the internal organs were also automatically scaled in proportion to the LBM and head dimensions [2].

To see the impact of body size on dose calculation, the organ-averaged dose of the male phantoms having the same height and different weight (i.e., H78.5W9.4, H78.5W10.6, and H78.5W11.9) were calculated and compared for the stomach, breast, and brain with different trends expected. Note that the stomach and breast with a large tissue weighting factor (=0.12) are scaled in proportion to the LBM, while the brain is scaled by head dimensions due to the fact that the brain is

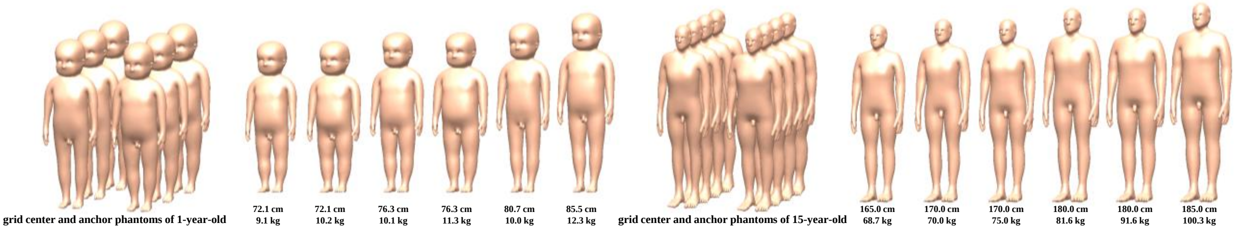

Figure 1. Body-size-dependent pediatric phantom library for some selected male phantoms.

located in the head. The phantoms were irradiated by monoenergetic broad-parallel beams of photon (i.e., 0.01–10,000 MeV) in antero-posterior (AP) geometry with the Geant4 Monte Carlo radiation transport code (version 10.06.p02) [12].

3. Results and Discussion

Figure 1 shows some selected 1- and 15-year-old male phantoms of the body-size-dependent pediatric phantom library, as examples. It can be seen from Figure 1 that automatically constructed phantoms as well as the grid-center and anchor phantoms realistically represent body size and body shape for various heights and weights. The height and weight of the constructed phantoms are well matched to the target values within 0.1% difference. For the secondary anthropometric parameters, the values are matched to the target values within 5% difference.

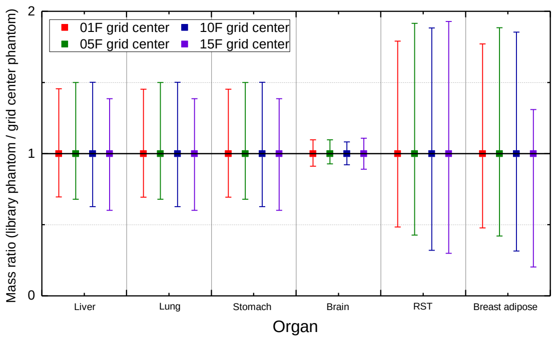

Figure 2. Mass ratio of library phantoms to grid-center phantoms for 1-, 5-, 10-, and 15-year-old female phantoms for liver, lung, stomach, brain, residual soft tissue (RST), breast adipose tissue.

Figure 2 shows the mass ratio of pediatric library phantoms to grid-center phantoms for some selected organs for female phantoms. The trunk organs (i.e., liver, lung, and stomach) show similar ratio values depending on the age of the base phantoms, ranging from 0.63 to 1.50 for ten years as examples, which is because the LBM was adopted to scale all these organs. For the brain, the ratios are close to unity (e.g., 0.89 to 1.11 for 15 years). This is due to the fact that the brain was scaled in proportion to the head dimensions which show weak correlation with body sizes. For the residual soft tissue (RST) and breast adipose tissue, significant different ratios are observed (e.g., 0.30– 1.93 for RST and 0.20–1.31 for breast adipose tissue for 15 years). These significant differences are because these tissues mainly or entirely consist of adipose tissues, which shows high dependency on body sizes.

Figure 3 shows the doses to stomach, breast, and brain of H78.5W9.4, H78.5W10.6, and H78.5W11.9 phantoms for photons in the AP direction. For the stomach, at energies less than 0.1 MeV, the H78.5W9.4 phantom shows the largest values, the maximum difference being 15 times at 0.01 MeV when compared with the H78.5W11.9 phantom. These results are due to the shielding effect of the body fat for the abdominal organs. On the other hand, for high-energy photons (>10 MeV), the opposite trend is observed. The maximum difference between the H78.5W9.4 and H78.5W11.9 phantoms was 1.22 times at 5,000 MeV. This opposite trend is due to the build-up region of high-energy photons. Compared with the stomach, the breast shows similar trend over the entire energy range. On the other hand, the breast shows smaller differences than the stomach at low energy photons, which is due to the fact that the breast-center-to-skin and breast-center-to-muscle distance ratios are preserved in constructing the library phantoms. Therefore, the distance from skin to breast does not change dramatically when compared to the distance from skin to stomach. Unlike the stomach and breast, the brain doses for all the phantoms are in good agreement. The differences are all less than 1%. These slight differences are again due to the weak correlation between the head dimensions and body sizes.

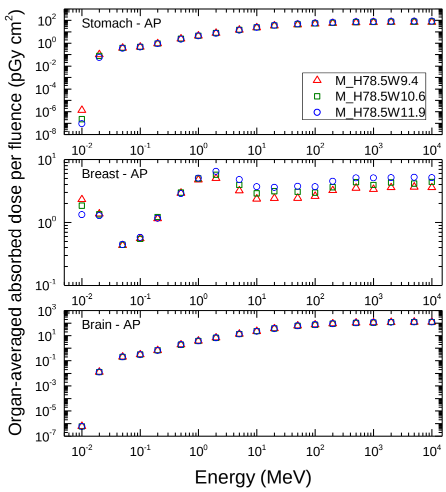

Figure 3. Organ-averaged absorbed dose per fluence (pGy cm^2) of H78.5W9.4, H78.5W10.6, and H78.5W11.9 phantoms for stomach, breast, and brain for photons in AP direction.

4. Conclusion

In the present study, the body-size-dependent pediatric phantom library consisting of 403 phantoms was constructed by deforming the ICRP pediatric MRCPs. The phantoms were automatically constructed by using the in-house C++ code, while matching the height, weight, and secondary anthropometric parameters. In addition, the internal organs were reasonably scaled by the LBM and head dimensions. To see the impact of the body size on dose calculation for children, the doses to stomach, breast, and brain in AP irradiation geometry for photons were calculated by using some selected phantoms. The significant differences by up to a factor of 15 for stomach were observed due to the shielding effect of body fat. These results suggest that the consideration of individual anatomy is necessary for individual dose calculation. However, the pediatric phantom library still has the restricted anatomy. Considering the fact that the individual anatomy data are mostly unknown, and the construction of individualized phantom is a labor-intensive process even if anatomy data are available, the phantom library is expected to improve the accuracy of dose estimates for children by taking the general body sizes and shapes of the individual into account.

REFERENCES

[1] Lee, H., et al., 2019. Percentile-specific computational phantoms constructed from ICRP mesh-type reference computational phantoms (MRCPs). Physics in Medicine & Biology, 64(4), 045005.
[2] Choi C., et al., 2020. Body-size-dependent phantom library constructed from ICRP mesh-type reference computational phantoms. Phys. Med. Biol. 65, 125014.
[3] Larson, D. B., Rader, S. B., Forman, H. P., & Fenton, L. Z., 2007. Informing parents about CT radiation exposure in children: it's OK to tell them. American Journal of Roentgenology, 189(2), 271-275.
[4] Huvanandana et al., 2018. An anthropometric approach to characterising neonatal morbidity and body composition, using air displacement plethysmography as a criterion method. Plos. One. 0195193.
[5] National health and nutrition examination survey (NHANES) IV (1999-2018)
[6] National health and nutrition examination survey (NHANES) III (1988-1994)
[7] People Size software (2008)
[8] Consumer product safety commission (CPSC) report (1977)
[9] The anthropometry survey of US army personnel (ANSUR) II (2012)
[10] The Korean Pediatric Society (TKPS) (2005)
[11] Ha S, *et al.*, Establishment of anthropometric dataset for construction of mesh-type pediatric phantom library, Spring Meeting of Korean Association for Radiation Protection, 2021.
[12] Allison J., Amako K., Apostolakis J., et al., Recent developments in Geant4, Nucl. Instrum. Methods Phys. Res. Sect. A., Vol. 835, pp. 186–225, 2016.