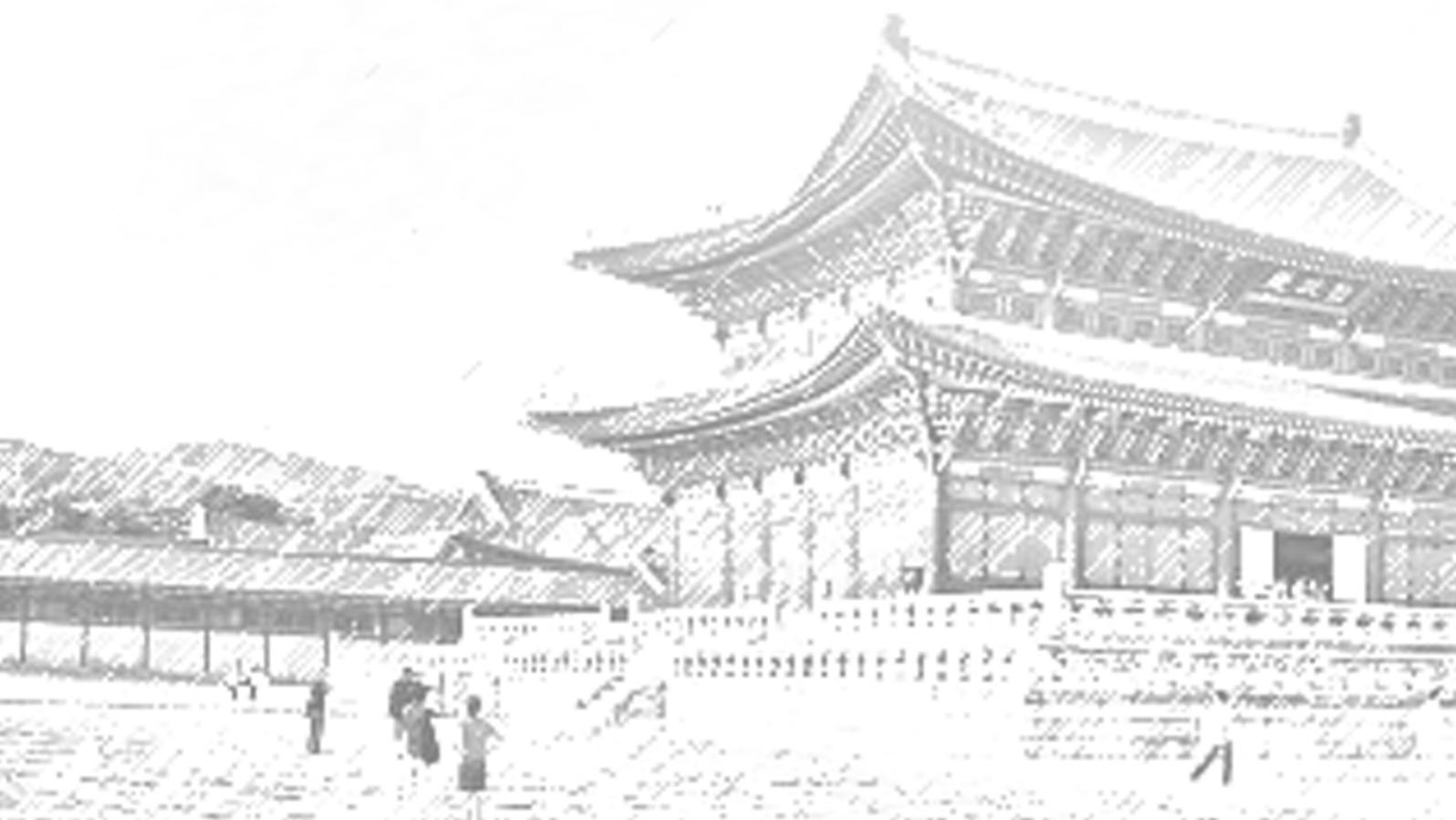# CP2015

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Construction of a Hybrid Computational Pediatric Phantom Library: Application to the Evaluation of the Effects of Body Habitus on Internal Radiation Dosimetry

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Abstract - In this work, a methodology is developed to modify the UF-NCI hybrid phantoms to generate a hybrid computational phantom library covering statistical distributions of body morphometry of the pediatric population. The targeted anthropometric parameters include the body weight, body length, body mass index (BMI) and sitting height/stature ratio (SSR) determined from reference databases of the National Centre for Health Statistics and the National Health and Nutrition Examination Survey. The UF-NIH phantoms were selected as representative anchor phantoms for the newborn, 1-, 2-, 5-, 10- and 15-yr-old children, respectively. A total of 1100 different male and female hybrid phantoms with 10th, 25th, 50th, 75th and 90th body morphometries were constructed. The constructed 125 5-yr-old habitus-dependent male phantoms with different body morphometries were used with MCNPX Monte Carlo transport code to investigate the effect of body habitus on the calculations of absorbed fractions (AF) and S-values of F-18 and the absorbed dose and effective dose of five ^{18}F-labelled radiotracers.

Index Terms - hybrid phantoms, radiation dosimetry

I. INTRODUCTION

Computational phantoms are commonly integrated with Monte Carlo codes simulating radiation transport inside the human body for the purpose of determining the patterns of radiation-tissue interactions enabling the calculation of the absorbed radiation dose in the human body from a variety of different medical radiation sources. However, the reliability of this methodology depends on the adopted computational model reflecting the physical characteristics (e.g. elemental composition, mass density, etc.) and anatomical features (e.g. shape, volume and size of total body and internal organs) of the human body. In this work, we developed a methodology and a C++ code to generate a large library of pediatric phantoms covering statistical distributions of body morphometry of the pediatric population to represent the human body of different habitus. The 10th, 25th, 50th, 75th and 90th body anthropometric parameters, including body weight, body length, BMI and SSR are used to remodel the anchor phantoms of the UF-NIH pediatric phantoms. A total of 1100 anthropometric computational phantoms are generated for the newborn, 1-yr-old, 2-yr-old, 5-yr-old, 10-yr-old and 15-yr-old male and female children. Monte-Carlo simulations coupled with phantom libraries can provide organ and tissue radiation dose estimations for a grid of habitus and weights, and by linear interpolation of the estimated dose for the actual anthropometric parameters of a person between the next data points of the grid, patient-specific organ dose, effective dose and cancer risks can be evaluated with high accuracy. We used the 125 developed habitus-dependent computational 5-years-old male phantoms to calculate the AFs and S-values of F-18 in 46 identified regions and evaluated the absorbed dose and effective dose of five ^{18}F-labelled radiotracers using Monte Carlo simulations. Dose comparisons were performed between habitus-dependent phantoms of different anthropometric parameters for estimation of the effect of body habitus on internal radiation dose.

II. METHODS

A. Computational phantom library

The National Health and Nutrition Examination Surveys (NHANES) data [1], including body weight, recumbent length, standing height, BMI and SSR, were used for parametrizing the pediatric population to generate habitus-dependent phantom libraries. The UF-NCI phantom series [2, 3] including the reference newborn, 1-, 5-, 10-, and 15-yr-old male and female models, were used as anchor phantoms for generation of phantom libraries of the newborn, 1-, 2-, 5-, 10-, and 15-yr-old male and female children. The schematic flowchart shown in Figure 1 illustrates the overall deformation process. The remodeling includes three basic components: the target anthropometric parameters obtained from the NHANES database; the anchor phantoms with well-defined anatomical structures that match reference data of the pediatric population; and the software tools that reconstruct the polygon mesh model from the

Figure 1. Flowchart of phantom remodeling for Monte Carlo simulations

corresponding voxel-based model, remodel the mesh phantom into a new one according to desired anatomical parameters and voxelize the generated mesh model into a new voxel-based model that is used as input for Monte Carlo calculations.

B. Dosimetry calculations

The 125 generated computational phantoms of the 5-yr-old male were used a input to the MCNPX Monte Carlo code to simulate the transport and interaction of emitted radiation from F-18. AFs and S-values of F-18 are calculated for 2116 source-target pairs of the 125 5-yr-old male models. The calculated S-values are then used to estimate the absorbed organ dose and effective dose from five ^{18}F-labelled radiotracers for the 5-yr-old male phantoms of different habitus.

III. RESULTS

A. S-values

Figure 2 shows the 5-yr-old male phantoms of the UF-NIH phantom series and constructed models with 10th and 90th weight, 10th and 90th BMI, 10th and 90th SSR, as well as with 50th weight, 50th BMI, 50th SSR, respectively. For most organs, the self-absorbed S-value has strong negative correlations with body weight, body height and sitting height and weak correlations with BMI and SSR (Table 1).
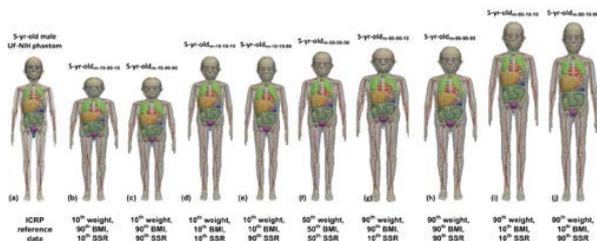

Figure 2. 3D visualization of computational phantoms of the 5-years- old male showing the original UF-NCI phantom and constructed phantoms of different habitus

Table 1. Pearson correlation coefficients between body habitus and self-absorbed S-Values of the 5-yr-old phantoms

Self-absorbed S-values of F-18	Weight	Height	BMI	SSR	Sitting Height
Adrenal	-0.92**	-0.73**	-0.01	0.16	-0.55**
Brain	-0.95**	-0.78**	0.02	0.22	-0.55**
Kidney	-0.92**	-0.74**	0.00	0.22	-0.52**
Liver	-0.85**	-0.82**	0.24*	0.26*	-0.57**
Lung	-0.90**	-0.75**	0.04	0.27*	-0.49**
Pancreas	-0.94**	-0.79**	0.04	0.19	-0.59**
Salivary Glands	-0.92**	-0.75**	0.01	0.21	-0.53**
Spleen	-0.89**	-0.74**	0.03	0.21	-0.52**
Thymus	-0.91**	-0.83**	0.15	0.16	-0.63**
Thyroid	-0.75**	-0.58**	-0.04	0.27*	-0.35**
Cortical bone	-0.99**	-0.84**	0.06	0.15	-0.65**
Spongiosa	-0.98**	-0.86**	0.09	0.14	-0.67**
Colon	-0.94**	-0.76**	-0.02	0.05	-0.65**
Gall Bladder	-0.93**	-0.71**	-0.08	0.13	-0.56**
Heart	-0.98**	-0.79**	-0.02	0.10	-0.63**
Small Intestine	-0.99**	-0.80**	-0.01	0.10	-0.65**
Stomach	-0.97**	-0.78**	-0.04	0.09	-0.63**
Urinary bladder	-0.95**	-0.76**	-0.04	0.10	-0.61**
Total body	-0.99**	-0.85**	0.06	0.15	-0.66**

*p < 0.01, **p < 0.001; SI refers to small intestine.

B. Absorbed dose and effective dose from radiotracers

The absorbed dose to 46 target organs from five ^{18}F-labelled radiotracers is calculated for the considered 125 computational phantoms. Table 2 lists the Pearson correlation coefficients of the relationship between body habitus and effective dose of five ^{18}F-labelled radiotracers.

Table 2. Pearson correlation coefficients for relation between body habitus and effective dose of ^{18}F-labelled radiotracers in the 5-years-old male phantoms

Radiotracers	Weight	Height	BMI	SSR	Sitting Height
^{18}F-Amino acids	-0.94**	-0.79**	0.05	0.22	-0.57**
^{18}F-Brain receptor substances	-0.95**	-0.80**	0.05	0.22	-0.57**
^{18}F-FDG	-0.98**	-0.86**	0.10	0.19	-0.64**
^{18}F-L-DOPA	-0.98**	-0.86**	0.12	0.17	-0.66**
^{18}F-FBPA	-0.97**	-0.86**	0.11	0.19	-0.64**

*p < 0.01, **p < 0.001; SI refers to small intestine.

IV. CONCLUSION

Based on hybrid computational phantoms, a habitus-specific phantom can be created to reflect person-specific body morphometries, thus offering an opportunity to perform person-specific dosimetry for various radiation exposure situations. A systematic study was performed to evaluate the internal dose characteristics of positron-emitting radionuclides and radiotracers in computational phantoms with different habitus. Most dosimetric parameters present high statistical correlations with total body weight and height and weak correlations with the BMI and SSR. The results support the general findings that the phantoms representing slimmer and shorter individuals receive higher absorbed organ doses. We expect that radiation dose estimates to subjects based on the most closely matched habitus-dependent phantoms has many potential applications. The detailed analysis of habitus- dependent dosimetric results for 5-yr-old children may also help frame the argument for individual patient dose assessment.

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