# Development of a library of adult anthropomorphic phantoms through more realistic scaling of organ masses

Azadeh Akhavanallaf[1], Tianwu Xie[1], Habib Zaidi[1,2,3,4†]

[1]Division of Nuclear Medicine and Molecular Imaging, Geneva University Hospital, CH-1211 Geneva 4, Switzerland.
[2]Geneva Neuroscience Center, Geneva University, CH-1205 Geneva, Switzerland.
[3]Department of Nuclear Medicine and Molecular Imaging, University of Groningen, 9700 RB Groningen, Netherlands
[4]Department of Nuclear Medicine, University of Southern Denmark, 500 Odense, Denmark
*Corresponding author: habib.zaidi@hcuge.ch

***Abstract*— Computational phantom libraries, representing anatomically and morphometrically differences between individuals, have been developed over the years to enhance the accuracy of radiation dose calculation from radiological procedures. In this work, a new anthropomorphic phantom library is developed covering not only different body morphometries among the population, but also modeling the anatomical diversities based on real data. Primary anthropometric parameters including standing height, total weight and body mass index are extracted from the latest publication of the National Health and Nutrition Examination Survey (NHANES 2011-2014) database. Organ masses information was culled from available scientific publications based on experimental studies. The International Commission on Radiological Protection (ICRP) male and female voxel models were selected as reference phantoms. A multiple correlation between organ mass and morphometric variables was derived for each organ to implement mass diversity for each organ into the phantom library. An automatic algorithm was developed for warping of the reference phantom to enable adjusting standing height and percentage of fat free mass by 3D scaling. Thereafter, organ masses were matched to the target values, and finally waist circumference and total body mass were adjusted. As a result, the diversity of organ masses due to the anthropometric differences deviate from the mean values by about 3-21%. For genital organs, this deviation exceeds 50%. Consequently, a total of 479 phantoms corresponding to seven age groups were constructed for both genders, thus fulfilling the criteria for representing a diverse adult population with different anthropomorphic and anatomical characteristics.**

*Index Terms*— ***Computational phantom, anthropomorphic phantom library, mass-scaled organs***

## I. INTRODUCTION

Computational phantoms were developed to accurately model radiation interactions within the human body using computational techniques such as Monte Carlo (MC) radiation transport toolkits, which provide useful information in radiation dose calculations and a number imaging physics research applications [1]. There are three generations of computational phantoms including stylized models in which organs were defined by simple surface equations, voxel phantoms constructed from tomographic medical images (CT, MRI, US) representing the human anatomy and boundary representation (BREP) phantoms taking the form of Non-Uniform Rational B-Splines (NURBS) or polygon mesh surfaces, which are flexible in terms of deformation and definition of motion [2,3]. To improve the accuracy of radiation dose measurements, habitus-specific phantoms were introduced as a size adjustable type of phantom constructed based on deformation of a reference phantom. A number of studies have focused on the design of anthropomorphic phantom libraries that have found applications in radiation dosimetry, radiation protection, noninvasive treatment, etc [2,4]. In this work, an anthropomorphic library with scaled organs representing the diversity of the population in terms of morphometric parameters was developed.

## II. METHODS

### A. *Correlation between organ masses and anthropometric parameters*

According to the trend of obesity among individuals, an updated database representing a realistic body morphometry distribution is required. In the current study, morphometric parameters of six age groups varying between 20 and 80 years plus one group over 80 years were obtained from the recently published NHANES (2011-2014) database.

In the absence of person-specific imaging data, the adopted approach consists in finding a correlation between organ mass and external anthropometric parameters. For this reason, organ masses are extracted from anthropometric parameters including age, standing height, body weight, and BMI of an individual. In this work, diversity of 13 organ masses including brain, heart, right and left lungs, liver, spleen, thyroid, right and left kidneys, pancreas and three genital organs for each gender were extracted from information based on autopsies and diagnostic measurements and used in the modeling process.

### B. *Methodology for automated deformation of phantoms*

An automatic algorithm was developed in house to remodel the reference phantoms into a number of new models using various anthropometric and anatomical data. Computer software was devised to implement the deformation algorithm schematically displayed in Figure 1.

## III. RESULTS

### A. *Analysis of the diversity of organ masses*

The diversity of organ masses depending on 4 anthropometric parameters is illustrated in Table 1.

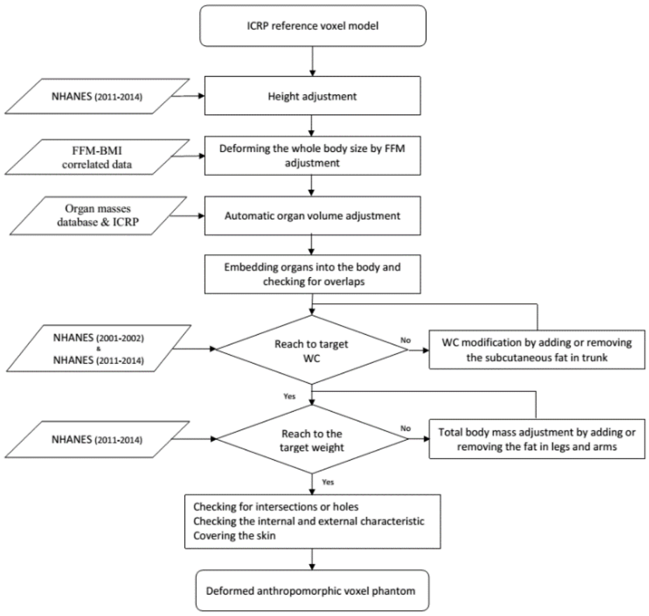


**Figure 1.** Flowchart of deformable voxel-based phantom modeling.

## B. *Deformed phantoms*

Figure 2 shows two male and female phantoms compared with the ICRP reference models to demonstrate the different morphometry of phantoms belonging to this library.

**Table 1**. Correlation between organ masses and anthropometric parameters for adult males and females.

| organs | Female organ mass (gr) | | | Male organ mass (gr) | | |
|---|---|---|---|---|---|---|
| | Mean ± SD | ICRP | Range | Mean ± SD | ICRP | Range |
| Brain | 1226.9±20.64 | 1300 | 1184.46-1265.37 | 1380.9±20.57 | 1450 | 1336.53-1419.57 |
| Lung | 491.83±9.2 | 475 | 471.32-502.27 | 621.24±17.17 | 600 | 587.15-649.48 |
| Kidney | 126.85±2.2 | 137 | 122.4-129.46 | 159.31±6.57 | 160 | 143.63-174.73 |
| Spleen | 149.52±12.13 | 130 | 127.32-180.99 | 197.01±22.04 | 150 | 153.60-250.99 |
| Pancreas | 99.672±3.618 | 120 | 92.87-105.97 | 123.73+3.59 | 140 | 114.87-127.55 |
| Liver | 1406.1±90.04 | 1400 | 1201.13-1601.02 | 1719.2+112.8 | 1800 | 1448.91-1942.58 |
| Heart | 595.95±9.618 | 620 | 571.42-605.24 | 879.71+14.80 | 840 | 847.05-902.42 |
| Thyroid | 17.455±0.8127 | 17 | 16.24-18.54 | 23.911+0.72 | 20 | 22.16-25.3 |
| Ovary | 3.64±1.988 | 5.5 | 1.872-6.76 | - | - | - |
| Uterus | 69.11+5.787 | 80 | 61.54-79.16 | - | - | - |
| Testes | - | - | - | 21.312+0.177 | 17.5 | 20.96-21.51 |
| Prostate | - | - | - | 32.289+7.33 | 17 | 21.50-42.15 |

## IV. CONCLUSION

An algorithm was developed to take into account the differences of organ masses along with the morphometric parameters to construct the voxel adult phantom (VAP) library by automatic remodeling of voxel-based ICRP adult reference phantoms. Data on 13 organ masses were culled from information gathered from autopsies and diagnostic examinations. The trend toward person-specific phantoms requires the incorporation of habitus-dependent phantoms in a comprehensive library considering the diversity of organ masses associated with morphometric parameters and classified in different somatotypes.

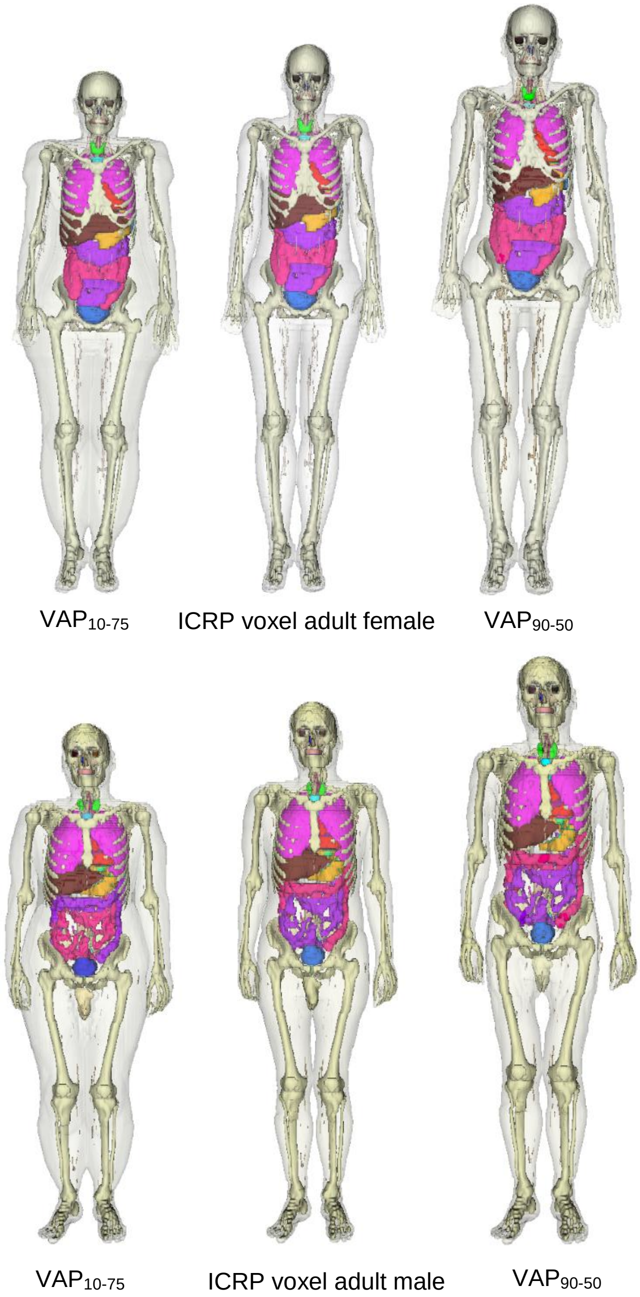


**Figure 2.** Frontal views of adult females at 10th percentile height and 75th percentile of weight ($VAP_{10-75}$), ICRP voxel adult female phantom, 90th percentile of height and 50th percentile of weight ($VAP_{90-50}$) for age 30-40 years and males at 10th percentile height and 75th percentile of weight ($VAP_{10-75}$), ICRP voxel male phantom, 90th percentile of height and 50th percentile of weight ($VAP_{90-50}$) for age 20-30 years.

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