

Yong Hum Na¹, Juying Zhang², X. George Xu^{1,2}

1. Biomedical Engineering, Rensselaer Polytechnic Institute, Troy, NY, 12180
2. Nuclear Engineering and Engineering Physics, Rensselaer Polytechnic Institute, Troy, NY 12180 email: xug2@rpi.edu

1. INTRODUCTION

Deformable and weight-scaleable whole-body adult patient models are needed for radiation dose assessment in various radiological procedures involving Computed Tomography (CT) imaging, radiation treatment, and bioassay of internal radiation contamination of workers. At RPI, several voxel patient models have been developed such as the VIP-Man that are not easy for size adjustment. Worldwide, about 40 such voxel models have been developed for adult and children (Zaidi and Xu 2007). These image-based models are more realistic than the stylized models developed 40 years ago at Oak Ridge National laboratory. However, voxel geometry makes the size adjustment difficult. In solid geometry modeling, the Constructive Solid Geometry (CSG) [1] is replaced by the Boundary REpresentation (BPREF) modeling techniques that are more powerful for applications involving surface deformation such as motion simulations or for morphing. BREF type of geometry offers greater control over the anatomical shapes and the tissue/organ surfaces could be flexibly deformed while maintaining various human internal organ information. Despite the advantage of the surface mesh modeling methods, tedious and time-consuming manual adjustment was necessary in our previous work on the pregnant female models [2]. This project developed an automatic deformation method to create size-adjustable RPI Adult Male/Female mesh models with dynamically deformable organs.

2. METHODS AND MATERIALS

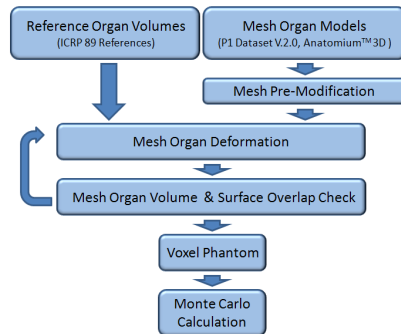


Figure 1. Schematic flowchart shows an overview of the mesh deformation algorithm for size-adjustable whole-body patient models.

The algorithm was implemented by MATLAB® 7.4 with original Anatomium™ 3D models whose organ geometries were morphed to agree within 0.5% with the International Commission on Radiological Protection (ICRP) reference male and female organ volume/mass data. These mesh morphing algorithms were used to automatically pre-modify the P1 dataset to have unique mesh information in each of organ meshes and deform the whole meshes based on the ICRP volume/mass reference [3-5] without unwanted surface overlapping through the special mesh overlap avoiding process. After all of mesh deformation, the size-adjustable whole-body patient mesh models (RPI Adult Male/Female) were transformed to the solid geometries in the voxel domain. These whole-body models consist of over 140 deformable organs (more than 500 mesh files) including their detailed internal anatomical information. These organs are explicitly defined for organ dose calculations using the Monte Carlo methods to define various radiological procedures. The primary features of this algorithm are summarized as follows:

- 1) **Mesh Preprocessing:** Each of organ meshes is optimized to have unique vertex and face. Each organ mesh file in the organ library is optimized before mesh deformation. After preprocessing, most of the mesh files become a close mesh type as well as the redundant vertices and faces are removed.
- 2) **Mesh Deformation:** Every vertex and face in each of pre-modified P1 mesh dataset is deformed to agree with the recommended ICRP volume data less than 0.5% using relocation of all the vertex positions through their normal vector direction.

- 3) **Mesh Collision Correction:** All mesh surfaces are considered to avoid unwanted overlap surface area using ray-casting method on each of deforming mesh surfaces with the given organ density information during the entire mesh morphing processing.
- 4) **Mesh Model Voxalization:** The size-adjustable RPI Adult Male/Female whole-body mesh models are transformed to solid geometries through the voxelization process.
- 5) **Mesh Model Validation:** Along with changing of person specific information, such as body size (height, weight) and major organs' volume, the mesh based RPI Adult Male/Female models are validated for the automatic size-adjustment and each of individual organs' deformation.

3. RESULTS AND DISCUSSION

3.1. Mesh preprocessing



	Total # of Vertices	Total # of Faces	# of Repaired Vertices	# of Repaired Faces
Mandible	10434	16472	1979 (19%)	0 (0%)
Teeth	22188	45168	908 (4.1%)	1741 (3.9%)

Figure 2. (a, b) Mesh deformations without/with mesh preprocessing of mandible and teeth meshes.

3.2. Mesh deformation with collision correction

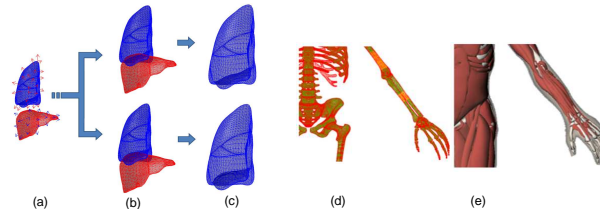


Figure 3. Mesh volume deformation (right-side lung & liver) illustrates the difference of the mesh deformation results of volume changing with surface collision correction method between right lung and liver. (a) mesh deformation with vertex normal vectors, (b) without (upper)/with (lower) surface collision correction method, (c) for right-side lung surface (zoomed in). Through this mesh deformation method, the most complicated bones and muscle structures are able to be described in agreement with the ICRP 89 reference. (d) 458 bone component structures (cavity; yellow, spongiosa; green, cortical; red), (e) 6 trunk muscle structures.

3.3. Mesh model voxelization

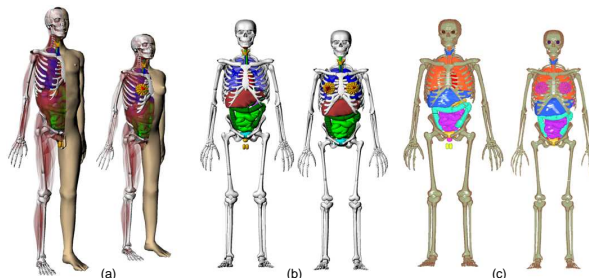


Figure 4. Mesh based size-adjustable RPI Adult Male/Female models have been voxelized for the purpose of performing dose calculation with well-validated Monte Carlo [6] radiation transport simulations. (a) the size-adjustable RPI Adult Male/Female, (b, c) illustration of the difference between mesh-based models and voxel-based models, respectively.

3.4. Validation of the RPI Adult Female portion of the body deformation

Code	AA	A	B	C	D	E	F	G
Cup size Range (cm)	10-12	12-14	14-16	16-18	19-20	20-22	22-24	24-26

Figure 5. The adjustment of breast size of the RPI Adult female model using the brassiere cup size definition (AA to G) by European clothes sizes standard (EN 13402)[7,8]

3.5. Validation of the RPI Adult Male/Female whole-body deformation

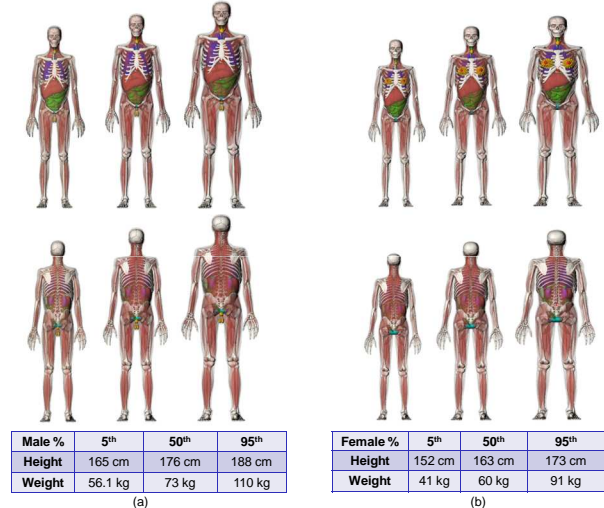


Figure 6. The size (height & weight) of the RPI Adult Male/Female models can be automatically scaled according to the percentile classification from 1999-2002 NHANES (National Health and Nutrition Examination Survey)[9], and also over 100 major organs of each specific percentile model can be individually deformed to agree with ICRP89 reference. This figure demonstrates 5th, 50th, 95th percentile person-specific (a) male models and (b) female models.

4. CONCLUSIONS

This study has demonstrated the feasibility to create whole-body deformable and percentile-scaled adult patient models in the future for applications that are person-specific by varying the weight, height, and portion of the body such as the female breast.

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