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WORKFLOW FOR CREATING A SIMULATION READY VIRTUAL POPULATION FOR FINITE ELEMENT MODELING

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ABSTRACT

A proof of concept workflow is demonstrated to easily translate 3D medical image data into finite element (FE) simulation ready phantom models. First, novel methods are used to drastically reduce manual segmentation time for a virtual population. Next, using Simpleware software, the segmented voxel datasets are extracted into faceted 3D CAD objects for tissues, while simultaneously maintaining conformal multi-tissue interfaces. Finally, the 3D CAD geometries are demonstrated to be readily compatible in a commercial 3D electromagnetic simulator, ANSYS HFSS.

NOMENCLATURE

Simulation, Meshing, Human Phantoms, Segmentation

INTRODUCTION

3D image-based meshing of multi-part structures from medical scan data (PET, SPECT, CT, MRI) continues to open up exciting new possibilities for the application of electromagnetic (EM), finite element (FE), and computational fluid dynamics (CFD) methods to a wide range of biomedical problems [1]. However, significant challenges to creating a population of simulation compatible human models have prevented them from becoming readily available for industry. These include: **1) Dataset Availability** – Due to health care industry privacy rules and the cost of creating a virtual population of MRI or CT scan data, very few readily available dataset repositories of human phantoms exist for industry use [2,3,4]. **2) Segmentation Difficulty** – Segmentation of scan datasets is extremely man-hour intensive. Depending on images and/or segmentation quality, effort is often measured by man-months or years for a single model. This time constraint has precluded patient specific and/or virtual population FE modeling. **3) Clean CAD Model Extraction** – If the CAD model contains coincident spline (NURBS) surface interfaces between tissues, meshing may be slowed significantly or prevented completely. Likewise, faceted volumetric meshes and CAD geometry must contain conformal face mapping between touching objects. Since traditional part-by-part meshing approaches risk gaps between, or node penetration into adjacent parts, manual and time consuming repair is required.

This paper demonstrates a potential solution to these challenges through a fast and efficient workflow that begins with newly available anatomical geometries, and culminates in a solved multi-object computational simulation. Using the new series of 4D extended cardiac-torso (XCAT) phantoms created by Segars and colleagues [5], we use ScanIP (Simpleware Ltd., Exeter, UK) to convert these datasets into multi-object simulation ready geometry files that are imported into HFSS (ANSYS Inc., Canonsburg, PA) for EM simulation and analysis.

METHODS

The 4D XCAT phantom [5] was developed for multimodality imaging research. Originally limited to the

Visible Human male and female adults, the XCAT was recently extended to create a vast population of 4D phantoms of varying ages from newborn to adult [6,7]. To overcome the time intensive bottleneck of the segmentation process, an innovative template-based methodology was developed to efficiently morph XCAT phantoms with thousands of defined structures to create 173 (58 adult and 115 pediatric) anatomically variable, highly detailed, full-body phantoms. A new phantom can be created in a matter of days with this new method, whereas previously, it could take up to a year. Each phantom is mathematically defined and can be voxelized into 3D images at any given resolution with each structure set to a user-defined intensity value. As an example for this work, an adult male XCAT phantom was voxelized at an isotropic resolution of 2 mm and three main tissue types were segmented and assigned to a unique intiger ID.

The voxelized data from the XCAT phantom was imported into ScanIP as a stack of 2D 32-bit greyscale images. Thanks to the pre-segmented nature of the XCAT data, anatomical geometries from the whole body models were automatically segmented and categorized into muscle, bone and soft tissues using the "pre-segmented data mask generator" tool.

For the sake of simplicity and model size, structures such as the arteries and veins were not included. Tissues other than bone and muscle were lumped together, spurious elements and gaps were removed using the ScanIP "Morphological Close" filter and various volumes were smoothed using a recursive Gaussian filter. A multi-part surface mesh was automatically generated where each tissue was conformal to all neighboring tissues with water tight, face-to-face contact between them defined by coincident nodes. The faceted solid model was then exported in the ACIS .sat format (Figure 1).

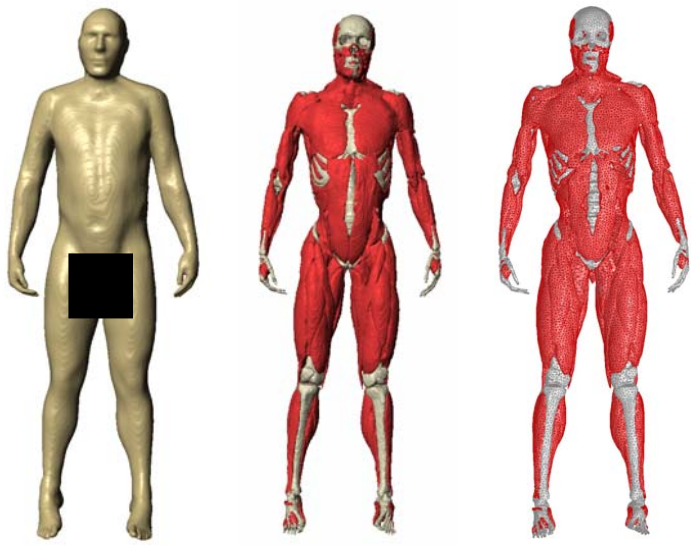

Figure 1. ScanIP reconstruction of the voxel data of soft tissues (Left), muscle/bone (Middle) and exported triangular faceted ACIS model with conformally contacting muscle/bone (Right).

SIMULATIONS

Once ACIS files were created for each tissue, the geometry was imported and assigned appropriate electrical, thermal, or fluids properties in the desired simulator. An electromagnetic FE simulation in ANSYS HFSS is demonstrated in Figure 2 (Left). This simulation included frequency-dependent permittivities and conductivities [8] that were mapped to each tissue via a script. A 300MHz incident plane wave source was applied as an excitation, which requires mesh discretization at the level needed for a 7T MRI. The water tight interface between objects greatly facilitates meshing. Meshes can be generated on each facet of the original CAD or the simulator may also use the Model Resolution feature to resolve the surface mesh to within a specified tolerance from the original. An example FE mesh is shown in Figure 2 (Right).

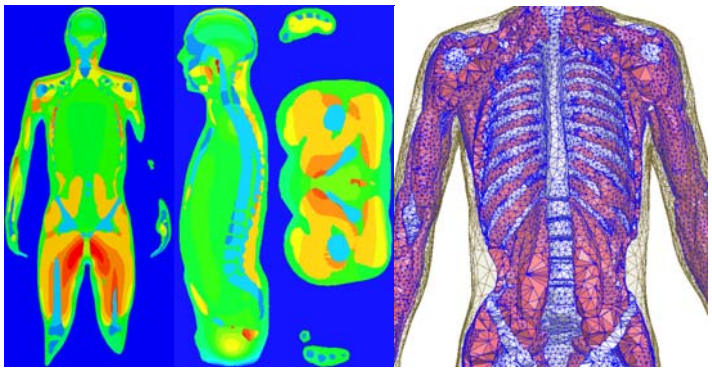

Figure 2. Local SAR distribution from 300MHz incident plane wave (Left) and ANSYS HFSS mesh of muscle/bone behind a clip plane (Right)

CONCLUSION

A proposed workflow from medical scan data through virtual human simulation was demonstrated with one individual from a newly available virtual population dataset. A semi-automated segmentation routine and automatic conformal CAD surface extraction algorithm provided the geometric models for the electromagnetic simulation. This proof of concept may be expanded upon to enable timely patient-specific biomedical simulations across a population of models in the XCAT phantom data set.

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