Using Subdivision Surfaces to Represent Bifurcations For Use in Finite Element Modeling of Aneurysms

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http://www.csm.ornl.gov/Internships/abstracts/RowenaOng.pdf

INTRODUCTION

- Abdominal Aortic Aneurysms (AAAs) are a leading cause of death in the U.S. Finite element models are being developed to help physicians predict location and risk of rupture.
- Current finite element models of AAAs do not include the iliac bifurcation, which may significantly affect fluid flow and wall stress (Fig. 1). Generation of a high-quality finite element mesh is difficult at the bifurcation.
- The purpose of this project is to generate a 3D representation of the iliac bifurcation from segmented computed tomography (CT) images so that a high-quality finite element mesh can be constructed.

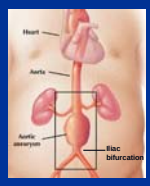

Fig. 1. AAA anatomy

Fig. 2. Mesh representation of an AAA. The lumen wall is represented by the inner mesh, and the thrombus wall is represented by the outer mesh. The thrombus is located in the volume between the two surfaces.

MATERIALS AND METHODS

- CT scans were segmented using Amira.
- A program was written in Matlab® to construct rough quadrilateral meshes for both the outer thrombus and inner lumen walls directly from the segmented CT images. Thrombus and lumen walls were constructed with corresponding faces so that a finite element mesh can be generated from the volume between the two surfaces.
- **Kobbelt's interpolatory quadrilateral subdivision** was used to refine and smooth the meshes constructed from the CT images. A C++ VTK (Visualization Toolkit) module implementing Kobbelt subdivision was extended to import data from Matlab®.

RESULTS

The preliminary results for one patient with an AAA are shown below:

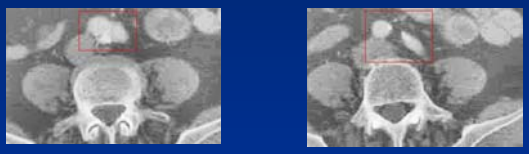

Fig. 3. CT images. The left image is an axial slice above the iliac bifurcation, the right an axial slice below the iliac bifurcation. The AAA is shown within the red box.

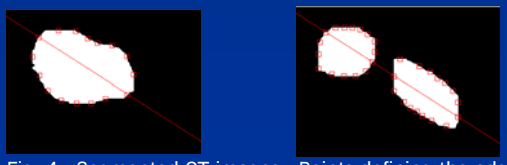

Fig. 4. Segmented CT images. Points defining the edges were found using simple geometric methods implemented in Matlab® (only the outer thrombus wall is shown)

Fig. 5. Rough quadrilateral mesh constructed from CT images using Matlab®

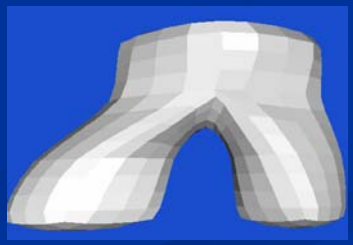

Fig. 6. Quadrilateral mesh refined by Kobbelt subdivision using C++

DISCUSSION

- **Advantages**
  - Re-meshing is avoided
  - High-quality quadrilateral mesh is generated directly from CT scans
  - Relatively inexpensive computationally
  - Quadrilateral mesh may be converted to NURBS (non-uniform rational b-splines) or other parametric representations
- **Disadvantages**
  - Method is specific to bifurcation geometry
  - Relies on already-segmented CT images
  - Relies on some *a priori* information

Future Work

- Use better algorithms to obtain points from segmented images
- If the outer thrombus or inner lumen walls are represented using more than one subdivision surface, determine if continuity can be maintained between the surfaces
- Reduce the amount of manually specified information needed
- Port Matlab® code to C++ to improve speed
- Generate a finite element mesh and run simulations in ADINA or other finite element modeling software

CONCLUSIONS

- When complete, this program will generate a smooth subdivision surface directly from segmented CT images, facilitating finite element analysis of AAAs at the bifurcation.
- Ultimately this will give physicians another tool to help predict risk of AAA rupture.
- This method could be applied to both vascular and pulmonary modeling to improve finite element analysis at bifurcations. One specific application is respiratory modeling of particles traveling in the lungs.

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