Constructing Hexahedral Meshes of Abdominal Aortic Aneurysms for Use in Finite Element Modeling

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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 with regular elements is difficult at the bifurcation.
- The purpose of this project: to generate quality hexahedral meshes of AAAs, including iliac bifurcation and distinguishing between the inner surface of the thrombus and the arterial wall that finite element analysis can be.

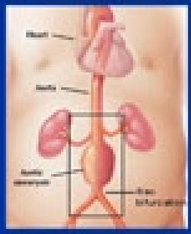
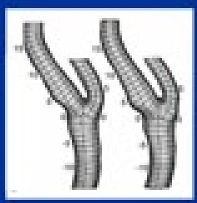


Fig. 1. AAA anatomy

Fig. 2. Mesh representation of an AAA. The thrombus is represented by the volume between the two surfaces.

METHODS

- CT scans were segmented and triangular surface meshes generated using Amira.
- Antiga and Steinman's method (2004) for automatically extracting parameterized representations of blood vessel walls was extended for AAAs.
  - **Extraction of centerlines**
    - Obtain approximation of medial axis by calculating the Voronoi diagram
    - Solve Eikonal equation over the Voronoi diagram using the fast marching algorithm
      - $\nabla T = 1 / R(x)$
    - Find centerlines by backtracking along path of steepest descent
  - **Generation of parameterized surface**
    - Longitudinal mapping
      - Solve following equation over the surface mesh using finite element method
      - $\Delta f = 0$ (where Δ is LaPlace-Beltrami operator)



    - Circumferential mapping
      - Use angular coordinates with respect to the centerline

  - **Generate hexahedral mesh**
    - Use sweeping algorithm
- Antiga and Steinman's implementation in the Visualization Toolkit (VTK) was extended using Visual C++ .NET.

RESULTS

Results for one patient's dataset:

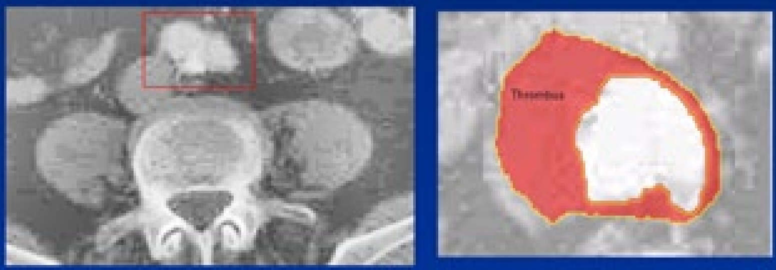


Fig. 3. CT images of AAA were segmented. (Only one slice shown here.)

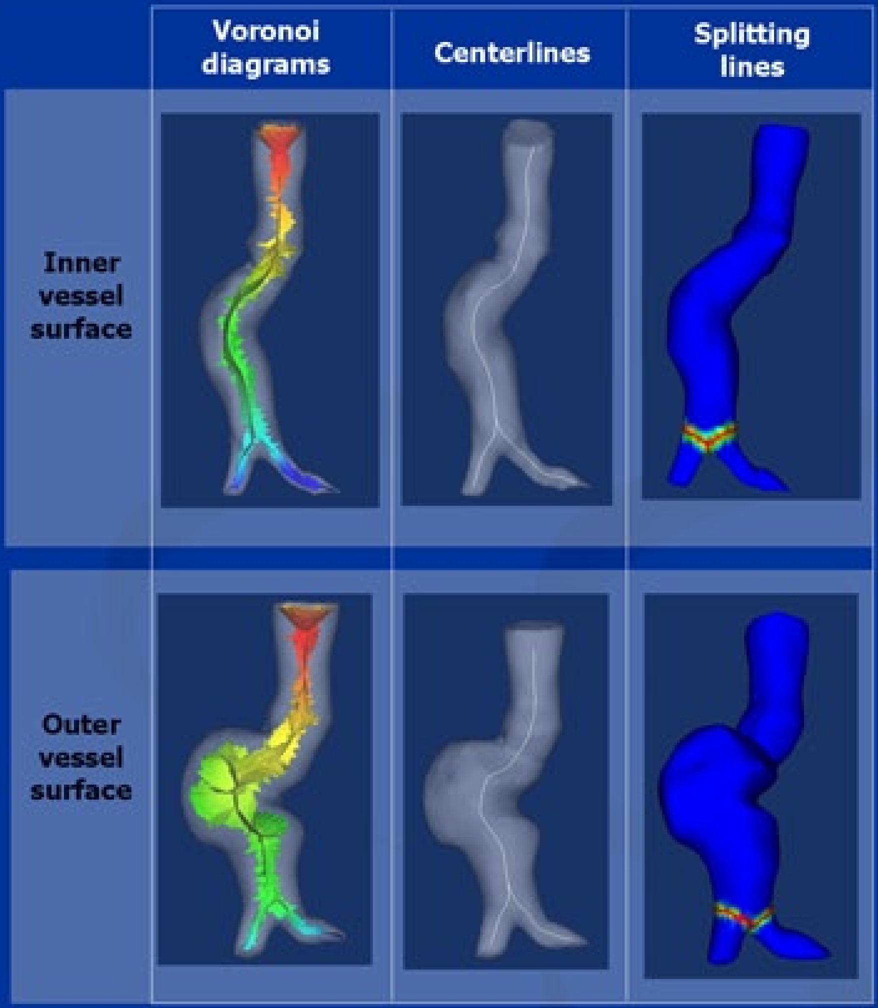


Fig. 4. Colors on Voronoi diagrams represent first wave arrival times.

CONCLUSIONS

- When complete, this program will automatically generate quality hexahedral meshes of AAAs, including iliac bifurcation and distinguishing between inner surface of thrombus and outer arterial wall.
- These meshes may be used in fluid-solid interaction models in the future, potentially giving more accurate results than fluid or structural models and providing insight into how the iliac bifurcation and thrombus affect AAA formation.
- This method could be applied to both vascular and pulmonary modeling to improve finite element analysis at bifurcations.

REFERENCES

- Antiga, L. and D. Steinman. 2004. Robust and Objective Decomposition and Mapping of Bifurcating Vessels. IEEE Trans. on Medical Imaging, 23(6):704-713.
- Antiga, L., B. Ene-Iordache, A. Remuzzi. 2003. Centerline Computation and Geometric Analysis of Branching Tubular Surfaces with Application to Blood Vessel Modeling.

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