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DIRECT FLOW ANALYSIS ON A RECONSTRUCTED 3D IMAGE OF A PHYSIOLOGIC PORCINE AORTIC TRIFURCATION

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ABSTRACT

The present study describes a detailed methodology, from 3D image reconstruction to flow analysis, for simulating the flow field in real arterial geometries. The procedure takes advantage of the latest state of the art technology in solid modeling, and is illustrated by application to a porcine aortic trifurcation. A Stereolithography (STL) format representation of the physical geometry is used in the Gambit™ (1998) preprocessor to create an identical, "virtual" geometry, which is subsequently meshed for flow analysis. With this simplified procedure, it is possible to take MRI or CAT scan images and perform computational flow analysis within physiologic passageways, using commercially available solvers.

METHODOLOGY

Image reconstruction: A 3-D computational image was obtained from the outlines of serial sections of a vascular cast of a terminal porcine aorta. The vascular cast was set in a polyester resin mold. Using a digital video acquisition system, registered cross-sectional images were acquired every 635 microns as the mold with the embedded cast was milled away using a conventional milling machine. The perimeter of each section was outlined manually. Approximately 60 points, uniformly spaced around each perimeter, were used to produce a point cloud representation of the actual geometry. This set of points was imported into I-DEAS Master Modeler™, where b-splines were used to smooth the perimeter of each section; splines in the longitudinal direction, serving as rails for the surfaces, were overlaid tangent to the cross-sectional splines. The surfaces representing the complex 3-D structure were generated from the splines using several lofting techniques. After surfacing, the geometry was translated into STL format (Fig. 1A). Using I-DEAS Rapid Prototype™ software, a faceted representation of the arterial region was created, consisting of 16924 facets (Fig. 1B) with a maximum absolute facet deviation of 0.01mm. Due to the presence of areas of extreme curvature in the model, minimization of the facet deviation was critical in capturing the profile of the modeled geometry. The STL model was then exported to Geomagic Wrap 2.1™, where the model was checked for overall integrity and inconsistencies in facet junctions, and was then imported into Gambit™ for FE mesh generation.

Meshing: An STL file contains information in the form of vertices, edges and triangular facets on the surface of the model. When an STL file is imported into Gambit™, the triangular mesh is obtained with the geometry. Gambit™ converts the mesh edges into topological edges, using a feature angle criterion. The feature angle may be assigned low or high values, depending upon the information to be extracted from the STL model.

The STL file was imported into Gambit™ using a feature angle of 90°. A high feature angle criterion was used to merge multiple faces into a single face. Subsequently, the imported triangular faceted mesh was deleted, whereas the geometry it represented was retained. This faceted geometry contained only one face covering one inlet and all the outlets. The face was then subdivided to separate the inlet and three outlets. In order to perform a flow analysis, the geometry was extended by five diameters at the inlet and outlets. Then, a suitable triangular mesh was generated over the faces of the geometry and the saved mesh was read into TGrid for improvements or modification.

To create a smooth hexahedral mesh (Fig. 1C), volume decomposition was needed, as the geometry contained adverse curvatures at the inlet, outlets and trifurcation. In Gambit, the geometry was divided into several zones and appropriate zones were stitched together to make a geometry that was suitable for hexahedral meshing. "Virtual" volumes were formed from the faces. The side faces of the geometry were made mappable. After ensuring that all the side faces were mappable, the volumes were checked for deformities. Skewness was reduced by smoothing both the surface and volume mesh, and boundary conditions were specified..

RESULTS

Flow analysis was performed for a constant inlet flow rate of 1000 ml/min and Re = 510. A no slip boundary condition was specified at the arterial wall. The fluid viscosity and density were 3.45 cp and 1.05 gm/cc, respectively. The pressures specified at the outlet planes determined the flow partition at the trifurcation. For this illustrative case, identical outlet pressures were specified for all the three vessels, resulting in a flow partition in which 48% exited through the common internal iliac artery, with the remainder divided almost equally between the two external iliac arteries. Sample velocity vectors and pressure contour plots in orthogonal planes are shown in Figs. 2A through 2C. Detailed results will be provided elsewhere.

If a tetrahedral mesh is sought, volume decomposition is not needed and the mesh can be created after the surface mesh file is read into TGrid. In TGrid, all the free nodes can be removed, and thus skewness of the triangular mesh may be reduced below 0.8.

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REFERENCES

Gambit™ Manual (1998) Fluent Incorporated, 10 Cavendish Court, Lebanon, NH 03766, USA

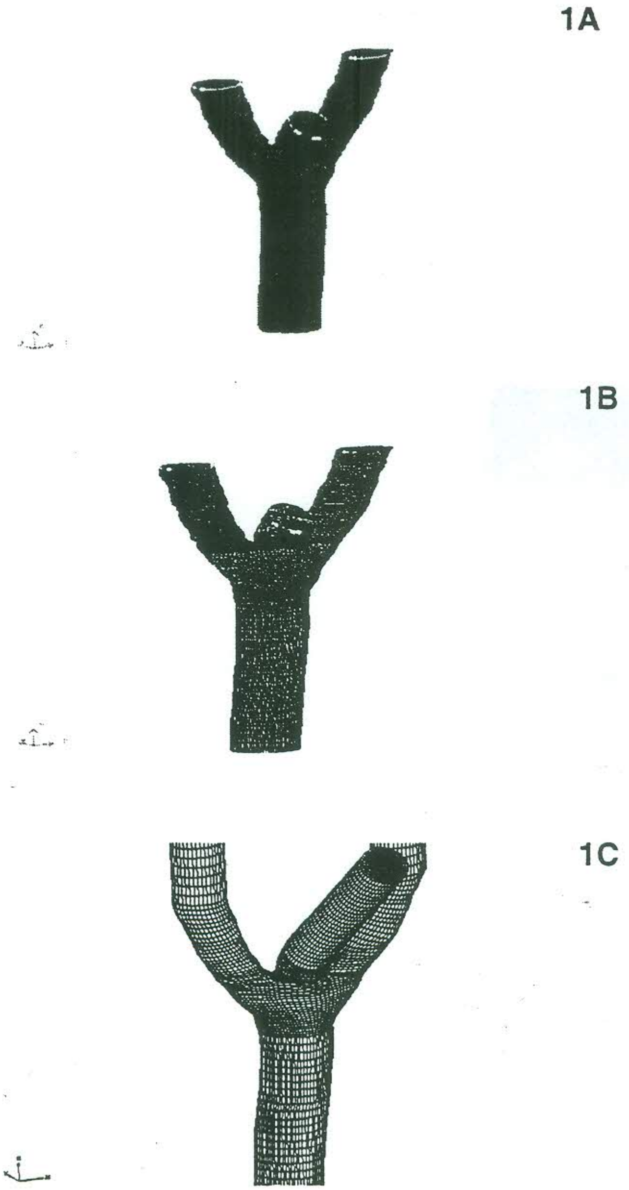

Fig. 1 Reconstructed image is shown in Fig. 1A; Faceted geometry is shown in Fig. 1B; Fig. 1C shows Gambit™ mesh.

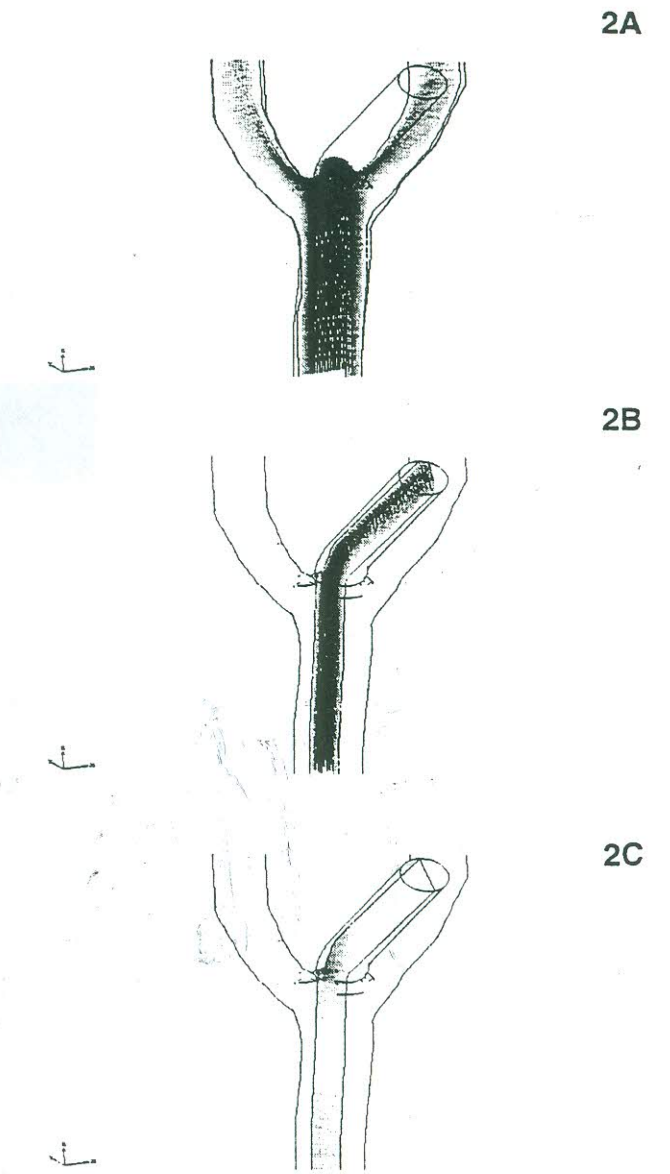

Fig. 2 Velocity vectors in orthogonal planes are shown in Figs. 2A and 2B; Pressure contour in the same plane as in Fig. 2B is shown in Fig. 2C.