Haemodynamics in Rigid Walled Abdominal Aortic Aneurysms

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Introduction

Abdominal aortic aneurysm (AAA) is a vascular disease involving a dilation of the aorta, the largest of the arteries. While the exact cause is unknown anyone can be affected and AAA may be present in up to 5.9% of the population aged 80 years [1]. Arterial disease, including AAA, is associated with disturbed flow regions where there are extreme shear stresses or shear stress gradients. Disturbed flows are also associated with the development of clotted blood, or thrombosis [2]. Pressure variations affect the risk of AAA rupture.

Aim

The aim of this work was to simulate the flow through real AAAs thus calculating the magnitude and gradients of the shear stresses and determining the pressure fluctuations.

Methods

Patient data Contrast enhanced X-ray Computed Tomography (CT) image data were obtained for each patient's abdomen.

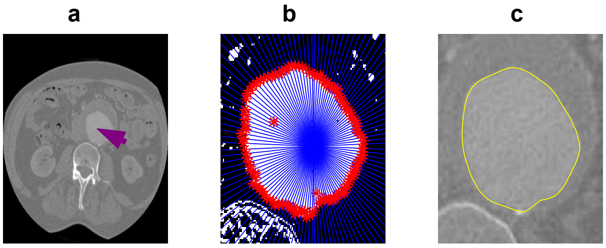

Figure 1: Segmentation. a) Whole slice showing lumen. b) Lumen region thresholded and with boundary marked. c) Smoothed boundary.

Segmentation The lumen was segmented on individual slices of the CT data with a semi-automatic threshold method, coded in Matlab (The Mathworks Inc.). Using a graphic user interface rectangular regions were selected on a number of slices throughout the data set. These rectangles were linearly interpolated throughout the data set and the maximum and minimum pixel values within each were used as upper and lower limits to threshold the image. Boundary points were found by locating where the pixel value along radiating lines dropped to zero. The contours were smoothed using a moving median and a moving mean in longitudinal and circumferential directions.

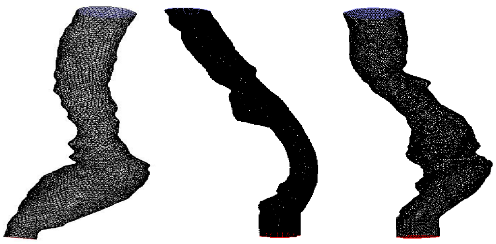

Figure 2: Examples of lumen meshes

Mesh generation The software Nuages by Boissonnant and Geiger [3] was used to make a triangular surface mesh using Delauney triangulation and saved in a format which could be imported into GAMBIT (Fluent Inc.), a computational fluid dynamics pre-processor. GAMBIT's automatic meshing tools were used to create tetrahedral volume meshes.

Computational Fluid Dynamics (CFD) FLUENT 6 (Fluent Inc.) was used to simulate flow through the arteries. Blood was assumed to be a Newtonian fluid with density 1040 kgm^{-3} and viscosity 0.00364 Pa sec. Steady state simulations were run on one of the geometries with both laminar and turbulent flow. Unsteady simulations, with realistic pulsatile velocity and pressure waveforms [4] as boundary conditions, and with a k-ω turbulence model were run on all arterial geometries.

Results

The steady state simulations did not converge suggesting that the flow in this geometry and with physiological Reynolds numbers is transient. Examples of results from one geometry with unsteady flow are shown in fig. 3 and the complexity of the flow including large recirculation regions can be seen from the streamlines. Results so far have shown normal blood shear stresses but low wall shear stresses on the lumen surface.

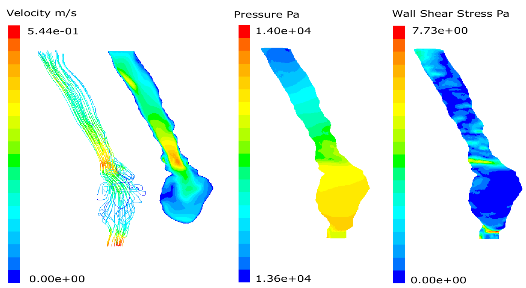

Figure 3:Example results (0.4s) left-right: streamlines coloured by velocity, speed in a plane, surface pressure, wall shear stress.

Conclusions

Aneurysmal aortas are tortuous and thrombosis occurs such that their lumen often have an undulating surface. The resulting flow is turbulent and complicated. The methods developed allow calculation of shear stresses and pressures in individuals with different AAAs and complicated flows.

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References [1] Renan Uflacker and Jacob Robinson. Endovascular treatment of abdominal aortic aneurysm: A Review. *European Journal of Radiology*, 11: 739-753, 2001. [2] C. J. Egelhoff et al. Model studies of the flow in abdominal aortic aneurysms during resting and exercise conditions. Journal of Biomechanics, 32: 1319-1329, 1999. [3] J-D Boissonnat and B. Geiger. Three-dimensional reconstruction of complex shapes based on Delauney triangulation. Rapport de recherché 1697, INRIA, 1992. [4] C. J. Mills *et al.* Pressure-flow relationships and vascular impedance in man. Cardiovascular Research, 4: 405-417, 1970.