Computation of Blood Flows in Arteries

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Introduction

The blood circulation is one of the most critical aspects of human circulation, and failures in it in the form of strokes and heart attacks represent one of the most common causes of death, particularly in industrialised societies. As humans age, plaque tends to build up inside arteries; this tendency can be exacerbated by poor diet. The plaque buildup leads to narrowing of the arteries and possible blockage; also plaque can break off and travel further along the circulation until it blocks a vessel further downstream. Plaque deposition is thought to be related to the forces exerted by the blood on the artery walls, referred to as the wall shear stress (WSS). WSS is also important in the development of aneurysms, where weakness in the artery wall leads to it ballooning out, and also the failure of grafts inserted eg. in bypass surgery.

Prediction of WSS is a difficult fluid dynamical problem on a complex geometry. Analytical solution would be impossible, and setting up realistic experiments difficult. For this reason, there is a great deal of interest in Computational Fluid Dynamics (CFD) techniques applied to determining the blood flow in general and WSS in particular. One aspect of this is the use of medical scanning techniques to generate the computational mesh for patient-specific calculations. This is an area that Exeter, together with the spin-off company Simpleware Ltd, are world leaders in [1]. We have developed tools for converting MRI scans of a patient to computational meshes, enabling us to perform CFD of arterial blood flows.

Flow in artery

As an example, MRI scans of a patient were obtained (by kind permission of the Royal Devon and Exeter Healthcare Trust). The scan comprises a series of 2d images of the upper leg (a typical example is shown in figure 1). This provides 3d information about the geometry which needs to be segmented – the relevant regions of the scan need to be flagged up – and then converted to a computational mesh. The segmentation is accomplished using a program called ScanIP, see figure 2, and then a second program (ScanFE) used to generate a mesh representing the red region which is the artery. This can then be used to compute the details of the blood flow, as shown in figure 3.

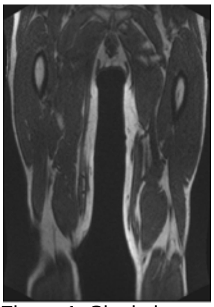

Figure 1. Single image from MRI of patient.

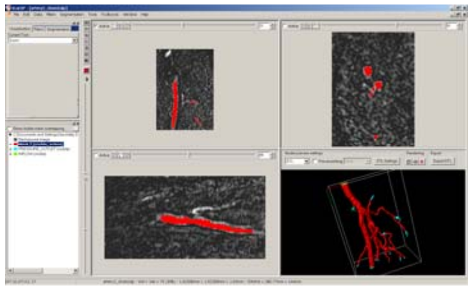

Figure 2. Screenshot of segmentation program ScanIP, used to identify and flag the regions of the geometry that are arteries.

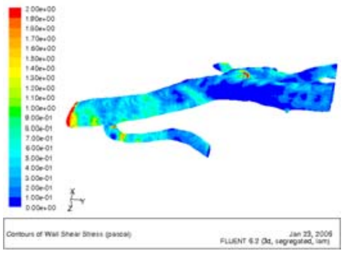

Figure 3. Wall shear stress in basic artery, calculated by Fluent (basecase500wss.tif)

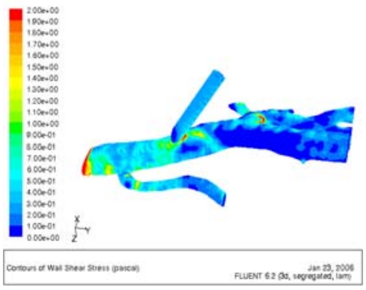

Figure 4. Wall shear stress in artery with bypass graft inserted using ScanCAD

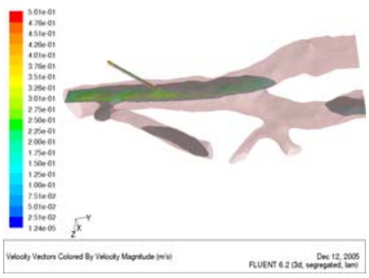

Figure 6. Calculation of flow generated by injection into an artery.

Predictive modelling

In addition to being able to compute the flow in an existing artery, we also have the tools to modify the geometry. A third program, ScanCAD, makes it possible to import a CAD model into the image stack and manipulate it [2]. This can be used to introduce further geometric elements into the model, such as a bypass graft (figure 4) or a hypodermic needle (figures 5, 6) [3]. This provides us with the possibility of undertaking predictive modelling, for instance to model the effect of implanting a stent into the artery to hold it open, before actually undertaking the operation.

Conclusions

CFD could be an enormously valuable tool in understanding the mechanics of blood flow in arteries. Using techniques pioneered in Exeter we have the opportunity to perform patient-specific modelling or even to predict the outcome of particular surgical operations.

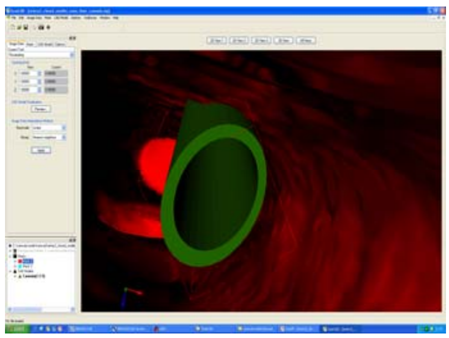

Figure 5. ScanCAD used to insert a hypodermic needle into the artery

References

[1] I.Weber and P.G. Young.`Automating the generation of 3d finite element models based on medical imaging data: application to head impact.' 2D Modelling: 23-24 April 2003, Paris, France, 2003.

[2] M.Puyou, E.Charriere, R.Streicher, and P.G. Young. `Post clinical assessment of implant performance: finite element models of an implanted femur and hip based on *in vivo* ct scan data.' 6th International Symposium on Computer Methods in Biomechanics and Biomedical Engineering, Madrid, 2004.

[3] G.Tabor, D. Tame, F. Pierron, P.G. Young, A. Watkinson, J.Thompson, `Patient-specific arterial flow simulation with additional geometrical elements', To appear in: Proceedings of ECCOMAS CFD 2006, September 5—8th, Egmont-Am-Zee, NL (2006)

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