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HEMODYNAMICS OF A STENOSED CAROTID BIFURCATION

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Abstract. A methodology for patient-specific computational 3D reconstruction and structured hexahedral meshing of the carotid artery bifurcation with a stenosis is described. The purpose of this work is the use of anatomically realistic blood flow simulations by the finite element method derived from in vivo medical imaging to make patient specific studies of flow phenomena associated with the development of atherosclerosis disease. Blood flow is described by the incompressible Navier-Stokes equations and the simulation is carried out under pulsatile conditions. The study of a diseased carotid bifurcation illustrates the extremely complex hemodynamical behaviour along the cardiac cycle.

1 INTRODUCTION

Recent non-invasive medical imaging data acquisition made feasible to construct three dimensional models of blood vessels. Colour Doppler ultrasound is inexpensive, widely accessible, fast and safe, and provides real-time images of endovascular structure; also measuring techniques have improved to provide accurate information on the flow fields. Validated computational fluid dynamics models using data obtained by these currently available measurement techniques can be very valuable in the early detection of vessels at risk and prediction of future disease progression.

In this work flow characteristics in a patient-specific carotid bifurcation with a stenosis are investigated by using direct numerical simulation. Since the carotid is a superficial artery and it is quite suited for medical ultrasound imaging, a semi-automatic methodology for patient-specific reconstruction and structured meshing of the left carotid bifurcation is presented. As hexahedral meshes compared to tetrahedral/prismatic meshes converge better, and for the same accuracy of the result less computational time is required [1] a tool to generate suitable structured hexahedral meshes for vascular modelling frameworks from Doppler ultrasound images is considered.

Blood flow simulation models [2] using pulsatile inlet conditions based on in vivo color Doppler ultrasound measurements of blood velocity, allow to compare numerical results with experimental data collected in clinical practice. The three-dimensional, unsteady, incompressible Navier–Stokes equations are solved with the assumptions of rigid vessel walls and constant viscosity (Newtonian fluid).

The ultimate aim of this study is the reconstruction of geometry and flow environment from in-vivo patient data, particularly at the extra-cranial carotid arteries, using Doppler ultrasound data.

2 RESULTS AND DISCUSSION

The accuracy and efficiency of the blood simulation is validated comparing velocities given by numerical calculations with experimental data collected in clinical practice. Left carotid artery bifurcation geometry, blood flow velocities, as well as, the flow wave form defining one cardiac cycle were obtained. Numerical velocities at different cross-section locations are compared with Doppler ultrasound measurements. In order to elucidate the role of carotid hemodynamics on plaque vulnerability WSS distribution at various flow phases are studied.

This work addresses the hemodynamical environment of a diseased carotid bifurcation concluding to be extremely complex during systolic phase and significantly different from that of a healthy carotid bifurcation.

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