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Steady state carotid flow simulations

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ABSTRACT

The present paper deals with the validated numerical simulation of steady incompressible viscous flow in a human carotid artery and its branch. This arterial tree, especifically the bifurcation of the common carotid artery (into the internal and external carotid arteries), is a well known site of atheromatous plaque formation. These plaques grow progressively leading to stenosis and can suddenly rupture causing instantaneous thrombi and emboli, thus infarction of irrigated tissues (stroke). Steady flow in the carotid artery occurs when the human heart, suffering from chronic heart failure, undergoes implantation of a small continuous-flow ventricular assist device (VAD). Abnormal wall shear stress, pressure and low washout regions may occur, which in turn could trigger plaque formation and growth [1, 2].

METHODS

A P1-P1 stabilized SUPG/PSPG/CONT finite element method was used to approximate the incompressible Navier-Stokes equations. Blood flows were simulated at Reynolds 320 for different but plausible outflow conditions corresponding to normal and abnormal flow separation at the carotid bifurcation. A sequence of nine grids was used to ascertain grid independence with a Zienkiewicz-Zhu a posteriori error estimator [3, 4]. These simulations agreed with experimental measurements obtained from fluid flow within a silicon model of the carotid. A time-resolved stereoscopic PIV test rig generated these experimental flow measurements.

RESULTS

We have observed that the flow field is extremely sensitive to inlet boundary condition. To compare the numerical prediction to the experimental measurements we have imposed at the inlet the measured velocity profile. The flow ratio is most often assumed to be equal to 7:3 (between internal and external branches) under normal conditions. However with VAD, the flow ratio has not been assessed. Therefore in the present work, the flow ratio ranges from 7:3 to 3:7. The latter corresponds to a severe stenosis in the internal carotid. The outflow boundary conditions do not markedly affect the flow in the trunk upstream from the transition zone. With a flow ratio 7:3, the flow field at the bifurcation divides between the two branches without strong recirculation in the carotid sinus. With decreasing flow ratio, high velocity isocontours in the transition zone moves toward the stem axis. With a flow ratio 3:7, the flow is deported into the external carotid increasing the strength of the separation region in the bifurcation segment. The maximum pressure point is located near to the maximum WSS on the carotid bifurcation. These values increase in intensity as the flow ratio rises from 7:3 to 3:7. The arterial wall undergoes remodelling under continuous flow after VAD implantation. An increase in WSS and stagnation pressure at this location favour further arterial remodelling.

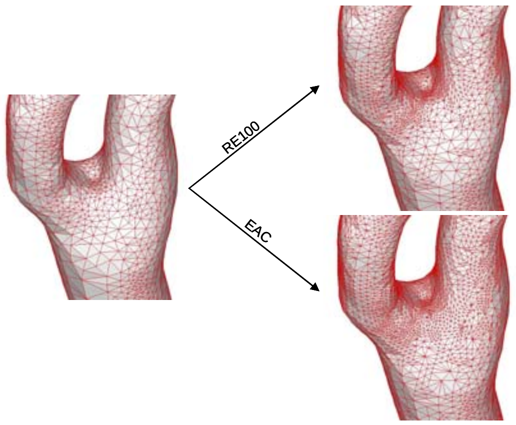

Figure 1 Mesh refinement

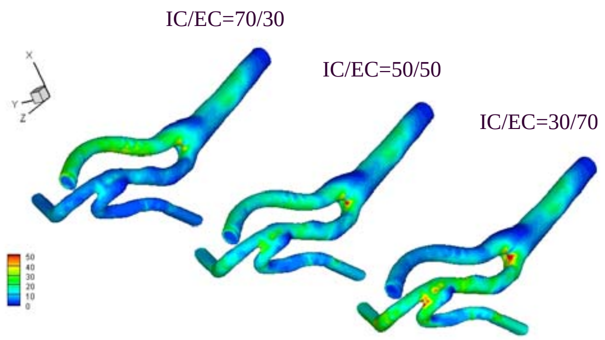

Figure 2 WSS variation for various flow rate ratios

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