Alteration in wall shear stress caused by non-axisymmetric flow in a fusiform abdominal aortic aneurysm

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Abstract

Blood flow in a model fusiform abdominal aortic aneurysm is simulated using a high-order computational fluid dynamics algorithm to explore the distribution of wall shear stress throughout the cardiac cycle and the three-dimensional structure and dynamics of the flow within the aneurysm. A linear stability analysis of axisymmetric flow solutions is performed to determine the conditions under which the flow is likely to preferentially adopt a non-axisymmetric structure. Three-dimensional simulations are conducted, revealing the structure of these flows, and calculations of wall shear stress throughout the aneurysm bulge and throughout the cardiac cycle are performed. The recorded wall shear stress distributions are analyzed in the context of aneurysm pathogenesis, and the spatial variation in wall shear stress (particularly in the azimuthal direction) is considered with respect to the potential for the asymmetrical growth of an aneurysm bulge.

Key words: Computational fluid dynamics, wall shear stress, aneurysm, flow stability, blood flow, circulation

1. Introduction

Aneurysms manifest as a localized enlargement of an artery, and are prone to abrupt and unexpected rupture, leading to incapacitation or death.[1] Recent attention has focused on the role of blood flow on aneurysm mechanics, characterizing the fluid mechanics within an aneurysm, and determining the fluid stresses imparted on the artery and aneurysm walls. Axisymmetric modeling[2] has shown that in fusiform aneurysms, the flow is dominated by a strong vortex ring, which develops in the bulge during the systolic phase of the heartbeat waveform. This study will employ three-dimensional analysis and simulation to investigate three-dimensional features of this complex flow system.

2. Methodology

The aneurysm is modeled as a sinusoidal bulge in an otherwise straight pipe,[2] and that reference should be consulted for details regarding the governing parameters and model validation. Flow is driven by a pressure gradient derived to reproduce a physiologically realistic pulse waveform. Two- and three-dimensional flows were computed using an established spectral-element method.[3, 4]

3. Results

From a linear Floquet stability analysis,[5] the flow described in[2] is predicted to be unstable to non-axisymmetric perturbations with an azimuthal wavenumber $m = 3$. Three-dimensional simulations were then conducted to confirm this result.

Figure 1 plots contours of wall shear stress magnitude over single a period from the saturated three-dimensional simulation. The contours indicate that the non-axisymmetric effects are most visible in the resting phase of the pulse cycle (left image). During the systolic phase (2^{nd} image) and beyond, where wall shear stress levels are highest, there is little wal shear stress variation in the azimuthal direction. Thus axisymmetric flow structures (such as the primary vortex ring generated in the bulge[(2)]) are the dominant contributors to the wall shear stress distribution.

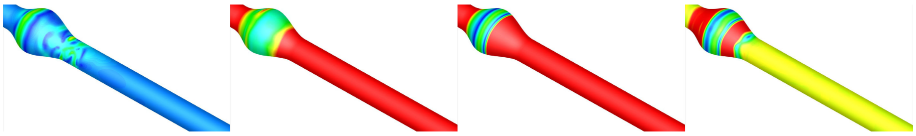

Figure 1: Magnitude of wall shear stress plotted for the model aneurysm at *Re* = 330. Flow is left to right, and one period is shown.

Figure 2 plots isosurfaces of streamwise vorticity, showing that during the resting phase (left image) non-axisymmetric structures develop in the aneurysm bulge. They are then expelled into the distal artery during systole. The implications of this on aneurysm growth will be explored in the Conference presentation.

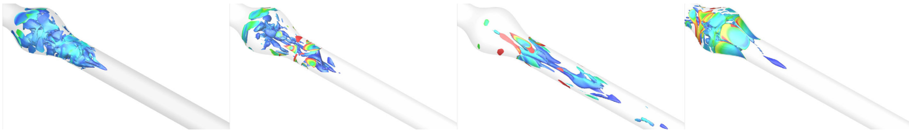

Figure 2: Non-axisymmetry in flow through a model aneurysm at *Re* = 330. Isosurfaces of streamwise vorticity are plotted, coloured by contours of shear rate magnitude.

4. Conclusions

A stability analysis and high-resolution non-axisymmetric computations of a flow representative of pulsatile flow through a fusiform human abdominal aortic aneurysm have shown that while the flow is non-axisymmetric under these conditions, wall shear stress is dominated by axisymmetric flow features. Three-dimensional flow develops in the aneurysm bulge during the resting phase, and is then ejected into the distal artery during the systolic phase.

Acknowledgements

Simulations were computed on the facilities of the Australian Partnership for Advanced Computing (APAC), thanks to a time allocation under the Merit Allocation Scheme.

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