Towards modelling thrombus formation in abdominal aortic aneurysms

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Introduction

In most cases intraluminal thrombus is found in Abdominal Aortic Aneurysms (AAAs), a pathological dilation of the infrarenal aorta (see fig. 1). These blood clots hinder blood-wall transport and alter the mechanical stimulation of endothelial cells, inducing arterial adaptation that can result in aneurysm growth.

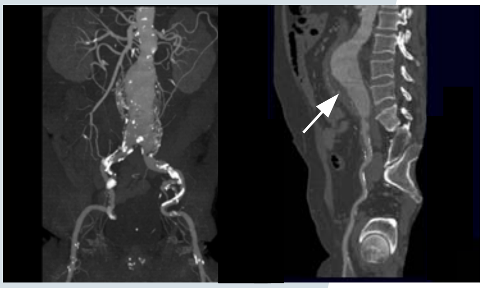

Figure 1 *Frontal (left) and sagittal (right) view of an AAA with intraluminal thrombus (see arrow). [Courtsey of Leiden University Medical Center, NL]*

Thrombus is formed by activation, adhesion and deposition of platelets under influence of various agonists (e.g. APD and Thromboxane III). Mathematically, these processes can be described by a set of coupled convection-diffusion equations (cf. [1]):

$$\frac{\partial c_i}{\partial t} + \boldsymbol{v} \cdot \nabla c_i = D_{iS} \nabla^2 c_i + S_i \qquad (1)$$

with c_i the concentration of the species involved, $\vec{v}$ the velocity, D_{iS} the diffusion coefficient and S_i the source term.

Methods

To obtain the necessary velocity field for eq. (1) we focus on solving the instationary Navier-Stokes equations:

$$\begin{cases} \rho\left(\frac{\partial \boldsymbol{v}}{\partial t} + \boldsymbol{v} \cdot \boldsymbol{\nabla} \boldsymbol{v}\right) - \eta \boldsymbol{\nabla}^2 \boldsymbol{v} + \boldsymbol{\nabla} p = \boldsymbol{0} \\ \boldsymbol{\nabla} \cdot \boldsymbol{v} = 0 \end{cases} \qquad (2)$$

with density ρ, dynamic viscosity η and pressure p. In SEPRAN [2] the validated (discontinuous pressure) 15-pts tetrahedra are used as benchmark to study the performances of the 10-pts tetrahedral in a continuous pressure formulation for an AAA geometry based on patient specific imaging data.

Results

In fig. 2 the 15-pts tetrahedron is validated by simulating a Womersley flow. The results of the AAA simulation (peak inlet flow of 6 [l/min], corresponding to $Re_R \approx 750$) are shown in fig. 3. Using the 10-pts tetrahedra the total number of nodal points is reduced by a factor 3. Total computing time is reduced significantly (over 10 times) while the results are comparable.

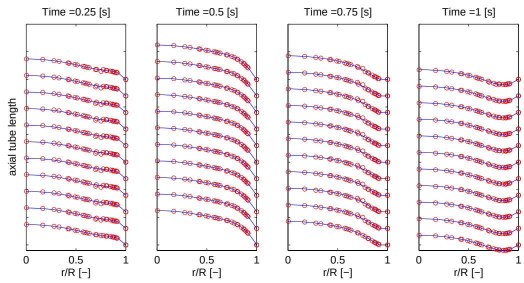

Figure 2 *Validation of the 15-pts tetrahedron by comparing the numerical (circles) and analytical (line) results of oscillating flow in a rigid tube with $Q_{max}(t) = 4$ [l/min] at t=0.5 [s].*

Discussion

The 10-pts tetrahedron provides a good alternative for the cost-inefficient 15-pts tetrahedral element. Moreover, they can also be used in a pressure-correction method (PCM) i.e. decoupling the continuity and momentum equation. Preliminary tests of oscillating flow in a tube show less CPU-time consumption per time step, but more time steps are needed.

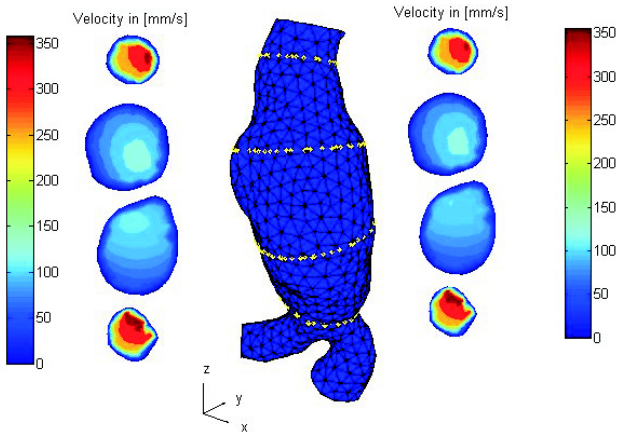

Figure 3 *Cross sectional contour planes of the velocity in an AAA at time $t = 0.5$ [s] for the 15-pts (left) and the 10-pts (right) tetrahedra.*

Future work

- ☐ Quantify the differences between 10-pts and 15-pts tetrahedron;
- ☐ Assessment of the PCM in physically and geometrically complex problems;
- ☐ Define model parameters for eq. (1).

References:

[1] SORENSEN, E.N. *Ann. Biomedical Engng vol. 27(4),pp. 449-458, 1999.*

[2] SEPRAN: User manual and standard problems, Ingenieursbureau SEPRA, 2006.

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