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Hemodynamics of Abdominal Aortic Aneurysm

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Introduction

Hemodynamics of abdominal aortic aneurysm (AAA) is presented. AAA is a permanent dilatation of abdominal aorta. The majority of AAAs contain intraluminal thrombi (ILTs) which have an active role in growth and remodeling of AAA [1], [2], [3].

Geometry of ideal fusiform AAA observed here is axisymmetric and cylindrical. In order to examine the impact of geometric variations on hemodynamics, different maximum luminal radii (R) of ideal fusiform AAA models were tested. The time averaged wall shear stress (TAWSS) is the parameter that can be used to predict ILT accumulation [4], [5]. Generally, ILT is accumulated when TAWSS on luminal surface is less than 0.4 Pa [6]. Using computational fluid dynamics, we can model blood flow and study the TAWSS through different AAA, and thus predict ILT accumulation. The aim of this study is to define minimal R (denoted by R_{cr}) where ILT starts to accumulate.

Models and Methods

Geometry models of AAA

The full geometrical model consists of the aorta segment, the aneurysm segment and the bifurcation segment (Fig. 1). The geometry of the aorta and the bifurcation segment are constant while the aneurysm segment evolves due to local elastin loss [7].

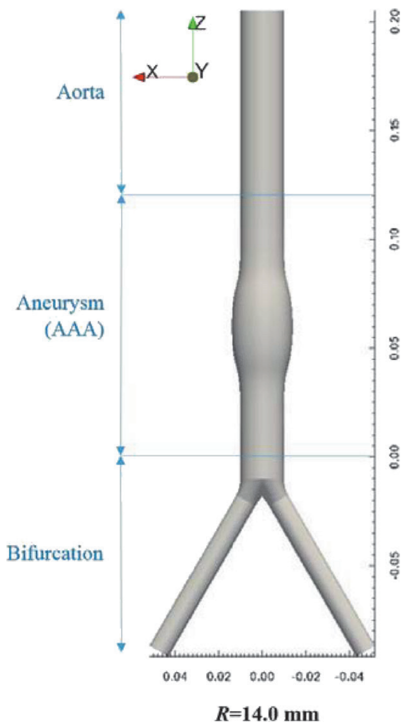

Fig. 1. Full geometrical model

Due to two symmetry planes, we examined 1/4 of the full model. The Salome software platform was used for geometry model generation and the final model is exported in form of a STL file describing its boundaries (inlet, outlet, symmetry and wall). After that the model is meshed in cfMesh program. The finite volume meshes for different R consists from 40000 to 50000 control volumes. Each of the finite volume meshes is hex-dominant. In the inner space of AAA model, the size of control volumes is 1 mm, while near the walls the size is 0.1 mm.

Hemodynamic simulation

Hemodynamic simulation was performed to determine whether an ILT will be deposited, as well as to predict the location and the amount of its accumulation. Thrombus accumulation is predicted based on TAWSS at the luminal surface lower than 0.4 Pa [6].

The time-dependent (pulsatile) volume flow with the parabolic velocity profile, based on data presented in Olufsen et al. [8], is defined on the inlet boundary. Blood is modeled as incompressible (ρ = 1060 kg/m^3) non-Newtonian fluid described by Carreau–Yasuda model [9], [10].

A numerical computation of the laminar transient flow was performed using SIMPLE algorithm for unsteady problems, implemented as “pimpleFoam” program in OpenFOAM software package. The discretization of the mathematical model was linear-upwind (second-order upwind), while the time integration method was Crank-Nicholson.

In each hemodynamic simulation five cardiac cycles were calculated with variable time step. The duration of one cardiac cycle was 1 second. First four cardiac cycles were used to evolve cyclicality of cardiac cycle and to accomplish velocity convergence. Results from the last (fifth) cycle were used to obtain the average wall shear stress (TAWSS). TAWSS distribution was computed on a 0.01 seconds sample (100 time values) within the fifth cardiac cycle and circumferentially averaged.

Results and Discussion

Fig. 2 shows TAWSS along *z* coordinate (*z*-axis is centerline of AAA) for different maximum luminal radii (R). The region with the lowest TAWSS corresponds to the region of a larger AAA diameter.

For R of 12 mm and 12.5 mm, the previously mentioned criterion of ILT accumulation is not fulfilled (no area with TAWSS lower than 0.4 Pa). At R of 13 mm the first TAWSS lower than 0.4 Pa appears and this is the maximum luminal radius (R_{cr}) where the first ILT will be accumulated. The larger ILT will be accumulated for R larger than R_{cr} due to a larger area of AAA where TAWSS is lower than 0.4 Pa. R of 14 mm also has

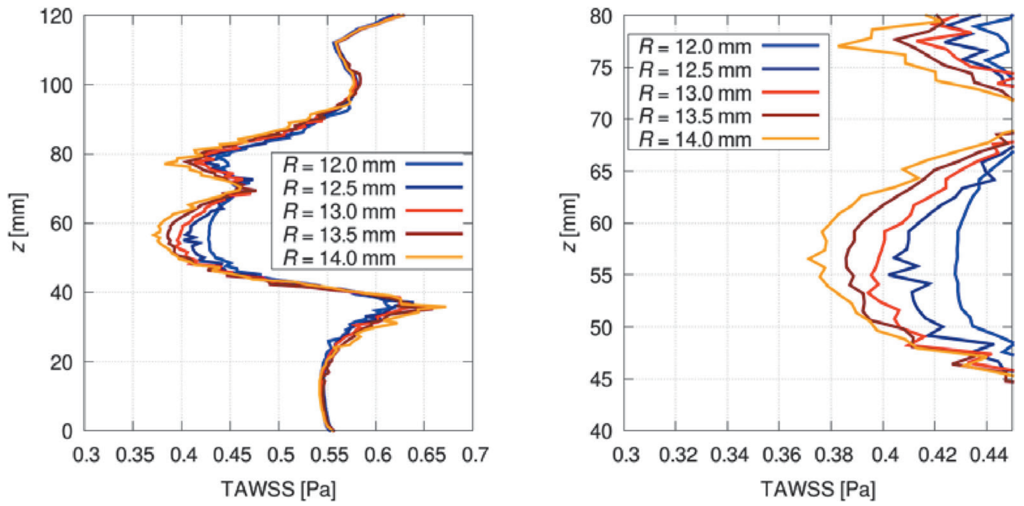

Fig. 2. TAWSS along z-axis (centerline) for different maximum luminal radii

the second area of AAA where TAWSS is lower than 0.4 Pa, thus the second ILT accumulation zone is generated. Fig. 3 illustrates the ILT accumulation zones (blue).

Conclusion

The hemodynamic analysis provides a valuable insight into the blood flow of AAA, providing a prediction of the ILT accumulation based on the time averaged wall shear stress (TAWSS). In the cases observed the critical maximum luminal radius was found to be from 12.5 to 13 mm. An increase in R results in an enlargement of the ILT accumulation zone. If R is greater than 14 mm, the second ILT accumulation zone occurs.

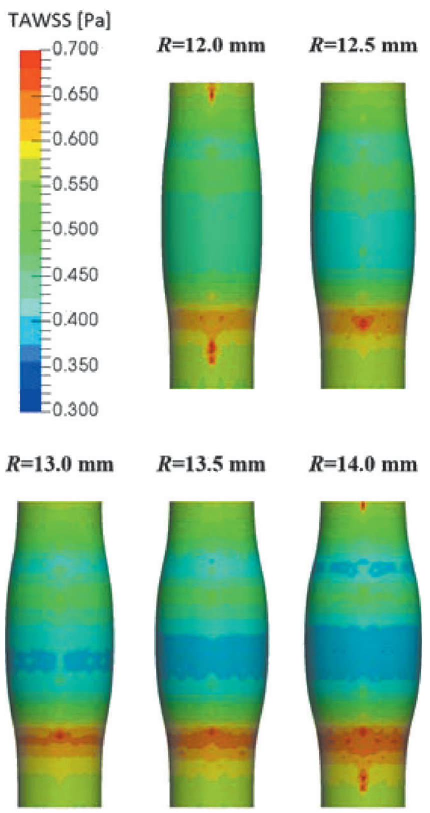

Fig. 3. TAWSS for different R

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