Study of cerebral aneurysms through experimental biomarkers and computational hemodynamics

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Introduction

Intracranial aneurysms (IA) is a devastating silent threat, not only because they often remain asymptomatic until rupture but also because of their association with high prevalence and mortality rate. However, the initiation and growth process is still unclear. With the progress on the availability of cerebral medical images, aneurysms are now being diagnosed on asymptomatic patients, turning this into a public health question. This suggests that more efforts and studies are needed to improve awareness of this disease, in order to help the clinical community to cope with it and to fight it.

We are interested in correlating two types of studies

Biochemicals (Experimental)

- Apoptosis
- Extracellular matrix degradation
- Endothelial damage

Hemodynamics (Computational Fluid Dynamics - CFD)

- Velocity
- Wall Shear Stress
- Convective transport
- Oscillatory Shear Index

Goal:

- Study and provide more accurate numerical simulations of hemodynamics in patient-specific cases;
- Investigate the correlation between hemodynamic and biochemical parameters within the aneurysm;
- Identification of the specific hemodynamic factors responsible at different stages of the aneurismal history may lead to improved therapy and possibly to prevention of this disease.

Methodology

To study the patient’s specific blood flow within aneurysms, medical images were provided by physicians. Before proceeding to the simulations, the 3D geometry to be rebuilt. One of the most important concerns in CFD modeling of Intracranial Aneurysms is to obtain a realistic geometry model based on each patient.

3D GEOMETRICAL MODEL

CT Images – Contrast enhancement and noise filtering

Segmentation – Surface Extraction and Selection of the ROI (remove side branches)

Surface smoothing (Taubin filter) and Creation of Extensions

Mesh Generation – GMSH (Unstructured tetrahedral elements = 4M)

NUMERICAL MODEL

Navier-Stokes Equations

\[ \frac{\partial u}{\partial t} + \nabla \cdot (u \otimes u) = - \nabla p + \nabla \cdot \tau + f \]

\[ \tau = \eta \nabla \otimes \nabla u \]

Boundary conditions

Mesh

Solutions

Results and Discussion

For each patient-specific case, a CFD study is done. Six cardiac cycles are simulated: five to completely stabilize the flow plus one more to obtain the results. The hemodynamic results show that values and their distribution over the aneurysms strongly depend on the geometry. In this example, we can observe that the values of the velocity and wall shear stress are very low inside the aneurysm. During the diastolic phase, the values are near zero, while in the systolic phase, the values are significantly higher in some areas. In these areas, an experimental biochemical evaluation with some biomarkers is performed to understand the correlation with the hemodynamic values.

Work in progress

- Hemodynamic and biochemical parameters have a pivotal role in the inception, evolution and even rupture of cerebral aneurysms;
- CFD measurements will be correlated to the experimental results of biomarkers on aneurysm sacs removed after clipping surgical intervention;
- By comparing the data on the ruptured aneurysms with those of unruptured ones, we may find the differences between the mechanical factors at play in the vessel wall;
- Longitudinal follow-ups will allow the evaluation of the aneurismal hemodynamics and correlate them to the morphological and clinical changes.

References


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