Identifying the hemodynamic characteristics for accurate prediction of aneurysm growth

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Introduction

The growth of a cerebral aneurysm (CA) has been established as a key indicator of aneurysm rupture. It is therefore important to differentiate stable from growing aneurysms during pre-interventional planning. We compare three CA models corresponding to the consecutive stages of growth of an aneurysm in a single patient. The goal is to take a significant first step to elucidate the mechanisms underpinning CA growth and determine accurate criteria for predicting aneurysm growth.

Methods

Patient-specific images of growing cerebral aneurysm at three different growth stages, acquired over the period of 40 months, are segmented and reconstructed. Pulsatile flow in the resulting aneurysm models is simulated using an in-house developed massively parallel CFD code (HARVEY). The CFD simulations are also validated against in vitro experiments using particle image velocimetry (PIV) measurements.

Results

The detailed analysis of intrasaccular hemodynamics shows that growing regions of aneurysms are characterized by flow instabilities and complex vortical structures. These areas correspond to dramatically lower (< 0.5 Pa) time average wall shear stress (TAWSS) along with a significantly higher oscillatory shear index (OSI) (> 0.1). Furthermore, our statistical analysis shows that the distance from unstable, recirculating flow structure from the wall of the aneurysm sac alongside TAWSS and OSI can be introduced as novel and accurate criteria to explain the hemodynamic conditions responsible for aneurysm growth and, more importantly, to predict the growth.

Conclusions

Our results suggest that aneurysm growth is more likely in areas with unstable, recirculating blood flow. In these regions, endothelial cells lining the aneurysmal wall are exposed to minimum values of TAWSS and a maximum value of OSI. Our study provides a fundamental contribution to establish new criteria to predict aneurysm growth which can facilitate the differentiation of stable and growing aneurysms during pre-interventional planning.

Learning Objectives

By the conclusion of this session, participants should be able to: 1) Differentiate stable from growing aneurysms according to discrepancies observed in hemodynamic factors. 2) Discuss to implement our introduced criteria for accurate prediction of cerebral aneurysm growth in early stage of the disease. 3) Identify an effective treatment to prevent the growth of small cerebral aneurysms which are classified as 'growing' based on our defined criteria.

References

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Figure 1

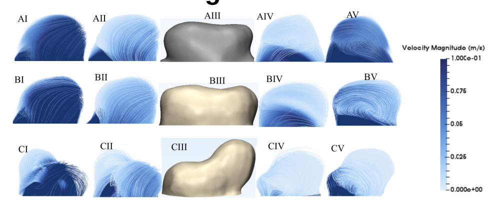

Figure 1. Flow pattern at diastole (AII, AIV, BII, BIV, CII, CIV) and systole (AI, AV, BI, BV, CI, CV) for early, mid, late stages.

Figure 2

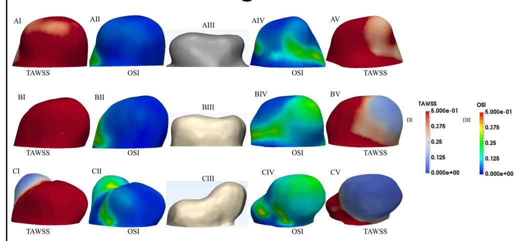

Figure 2). A-C) Time average wall shear stress and oscillatory shear index distributions for early, mid, late stages, respectively. The first column from left and right show TAWSS, and the second from left and right show the OSI. Note that D demonstrates the color bar of TAWSS and OSI, respectively.