Hemodynamic and Morphological Characteristics of a Growing Patient-Specific Cerebral Aneurysm

Mahsa Dabagh; Priya Nair; John Gounley; David H. Frakes PhD; L. Fernando Gonzalez MD; Amanda Randles
[Department of Biomediacl Engineering, Duke University, Durham, NC 27708]

CNS 2017 ANNUAL MEETING
BOSTON, MASSACHUSETTS
OCTOBER 7–11, 2017

Introduction

Aneurysm growth rate has been suggested as an indicator of eventual rupture, and identified as a potential risk factor for rupture. The ability to predict aneurysm growth requires a clear knowledge of the underlying mechanisms, which remain incompletely understood in part due to lack of patient-specific data describing the stages of aneurysm progression. The goal of this study is to take a significant first step to elucidate the mechanisms underpinning cerebral aneurysm (CA) growth.

Methods

Anatomical cerebral aneurysm geometries are segmented and reconstructed from patient-specific computed tomography angiography (CTA) datasets, at three different growth stages (namely the early, mid and late stages). Flow in the resulting aneurysm models are simulated using an in-house developed massively parallel CFD code (HARVEY). Clinically relevant hemodynamic parameters are then examined both qualitatively and quantitatively. The CFD simulations are also validated against in vitro experiments using particle image velocimetry (PIV) measurements.

Methods (Continued)

Furthermore, a part-comparison analysis was conducted to quantify morphological displacement between 3D models of CA growth stages. The calculated displacements between early and mid, and mid and late stages quantify variations among the geometries.

Results

Our detailed analysis of local hemodynamic factors including flow pattern, vorticity, wall shear stress (WSS), time average wall shear stress (TAWSS), oscillatory shear index(OSI) suggests that there is a strong correlation between areas of aneurysm growth and hemodynamic features, during the entire cardiac cycle. Growing regions of the aneurysm are characterized by flow-instabilities, flow impingement, and complex 3D vortical structures. Extremely low velocity occurs at the center of vortex where it correlates strongly with growing regions of growing CA.

Results (Continued)

These areas correspond to dramatically lower values (< 0.4 Pa) of time average wall shear stress (TAWSS) and lower values (0.1 Pa) wall shear stress (WSS), significantly higher (> 0.3) oscillatory shear index (OSI), and positive vorticity. The Spearman's rank correlation of local displacements with WSS, TAWSS, and OSI is found to have a two-tailed p = .0001.

Conclusions

Our study provides a fundamental contribution which details how disruption in hemodynamics is associated with aneurysm progresion. Our results suggest that aneurysm growth is more likely in aresa with unstable, recirculating blood flow. In thiese regions, endothelial cells lining the aneurysm wall are exposed to low values of wall shear stress and vorticity. Theis knowledge can be used as potential tool to differentiate stable from growing aneurysms during pre-interventional planning.

Learning Objectives

The significant implication of our findings is to take a first step to elucidate the mechanisms underpinning cerebral aneurysm growth, which can lead to depict reliable creteria for predicting the aneurysm growth.

References

1. Chalouhi N, Hoh BL, Hasan D. Review of cerebral aneurysm frmation, growth, and rupture. Stroke 2013, 44: 3613-3622.
2. Boussel L, rayz V, McCulloch C. Aneurysm growth occurs ar region of low wall shear stress: Patient - specific correlation of hemodynamics and growth in a longitual study. Stroke 2008, 39: 2997-3002.
3. Tanoue T, Tateshima S, Villablanca JP, Vinula F, Tanishita K. Wall shear stress distribution inside growing cerebral aneurysm. AJNR Am J Neuroradial 2011, 32: 1732-1737.
4. Sforza DM, Kono K, Tateshima s, Vinuela F, Putman C, Cebral RJ. Hemodynamics in growing and stable cereberal aneurysms. J Neurointervent Surg. 2016, 8: 407-412.
5. Randles A, Draeger EW, Bailey PE. massively parallel models of the human circulatory system . J Comp Sci. 2015, 9: 70-75.

Figure 1

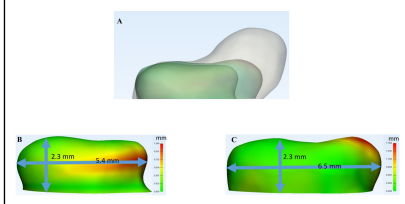

Figure 1. A) Anatomical variations between the three investigated aneurysm models. B-C) Displacement maps between B) early and mid stages, C) mid and third stages.

Figure 2

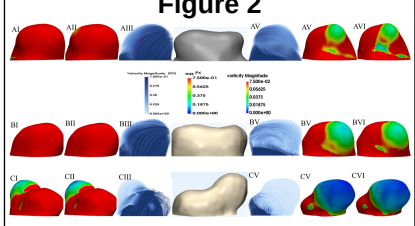

Figure 2. Flow pattern, wall shear stress, and vorticity distribution for all three growth stages of the aneurysm at systole. AI-VI) early stage, BI-VI) mid stage, CI-VI) late stage. Note that the first column from left and right show vorticity, the second from left and right show the wall shear stress, and third from both direction shows the flow pattern.