High Inclination Angles Lead to Flow Recirculation and Aneurysmogenic High Positive Wall Shear Stress Gradients in Cerebral Bifurcations

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Introduction

Arterial bifurcation geometry determines the local hemodynamic environment and has been previously identified as a predisposing factor for aneurysmal presence. Bifurcations harboring aneurisms have wider angles and more pronounced inclination compared to controls. We sought to determine the effect of the bifurcation inclination angle on the vessel hemodynamics and analyze its role in aneurysm formation.

Methods

Bifurcation parametric models were created at increasing bifurcation angles (60°-120°) and degrees of inclinations (30°-90°) between parent and daughter vessels. 3D rotational angiography of 4 MCA bifurcations (3 aneurysms, 1 controls) were available for computational fluid dynamic (CFD) simulations at and around the bifurcation apex. Wall shear stress (WSS) and WSS gradients (WSSG) were analyzed at the apex in all models.

Results

Higher inclination angles induce flow recirculation at the inclination elbow, starting from an angle of 45°. At inclinations angles larger than 60°, flow reversal is revealed in time-average WSS. Increasing the inclination angles results in a widening of the reversal area and the formation of recirculation focal points at the apex leading to lower WSS, but increasing positive WSSG. Wider bifurcation angles magnifies this phenomenon and leads to well-developed vortical structures at bifurcation angles wider than 120°. High inclination angles in patient-derived data show that bifurcation harboring aneurysms are characterized by strong flow reversal, in contrast to the control model.

Conclusions

High degree of inclination between parent and daughter vessels at cerebral bifurcations triggers a particular blood flow pattern characterized by flow reversal and formations of recirculation focal points. This phenomenon leads to the development of aneurysmogenic positive WSSG as a function of angular geometry, and provides a mechanotransductive link to aneurysm development. This suggests therapeutic strategies aimed at altering underlying unfavorable geometry and deciphering the molecular endothelial response to shear gradients in a bid to disrupt the associated aneurysmal degeneration.

Learning Objectives

By the conclusion of the presentation, the participants should be able to 1)Understand concepts of bifurcation geometry and their effects on hemodynamics,2)Become familiar with patient-based modeling,

3)Gain familiarity with vessel wall and cellular mechano-transduction and their effects on vessel remodeling and disease

References

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3-Baharoglu MI, Lauric A, Safain MG, Hippelheuser J, Wu C, Malek AM. Widening and high inclination of the middle cerebral artery bifurcation are associated with presence of aneurysms. Stroke. 2014 Sep 1;45(9):2649-55.

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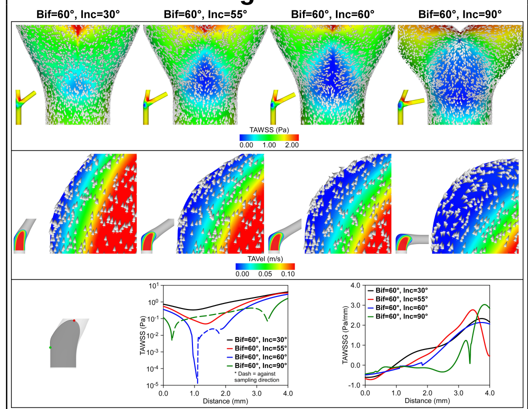
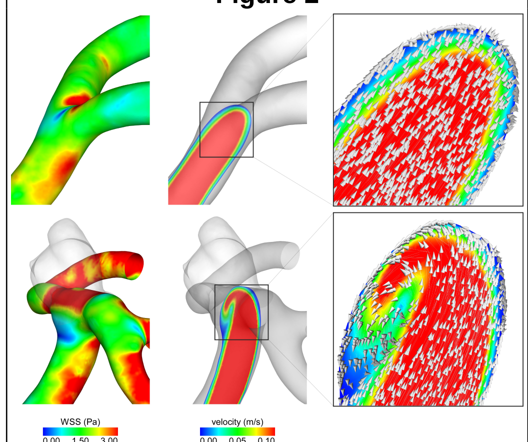
Figure 1



Effect of the inclination angle on bifurcation hemodynamics. Top row: time-averaged wall shear stress (TAWSS) distribution on parametric models with increasing bifurcation inclination angles. Middle row: detail of velocity vectors at apex show the effect of inclination angle on flow hemodynamics. Bottom row: plotting of TAWSS and TAWSS gradients for bifurcations with increasing inclination angles.

Figure 2



Analysis of rotational WSS on patient-derived data. Top row: healthy bifurcation with low inclination angle. Bottom row: aneurysmal bifurcation with high inclination angle. Detail of velocity vectors at apex show the effect of inclination angle on flow hemodynamics.