Wide Bifurcation Angles Induce Flow Recirculation and High Rotational WSS Component Distal from the Bifurcation Apex

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Introduction

Cerebral arterial bifurcations represent preferred sites for aneurysm formation, especially when associated with variations in divider geometry. Wider bifurcation angles were previously correlated with aneurysm presence, potentially due to increased hemodynamic insult acting outside of the protection of the medial pad (narrow band of tightly packed collagen fibers at bifurcation apices). We hypothesized that higher bifurcation angles are correlated to stronger flow recirculation in the bifurcation region migrating towards daughter branches.

Methods

3D rotational angiograms of 13 MCA bifurcations (6 controls) and parametric models with increasing bifurcation angles (45° to 240°) were analyzed using computational fluid dynamic (CFD) simulation. Wall shear stress (WSS) vectors along cross-sectional planes distal to the bifurcation apex were decomposed as rotational WSS (in plane vectors), and normal WSS (orthogonal to plane vectors). Rotational WSS (RWSS) and RWSS gradients (RWSSG) were evaluated at the apex region.

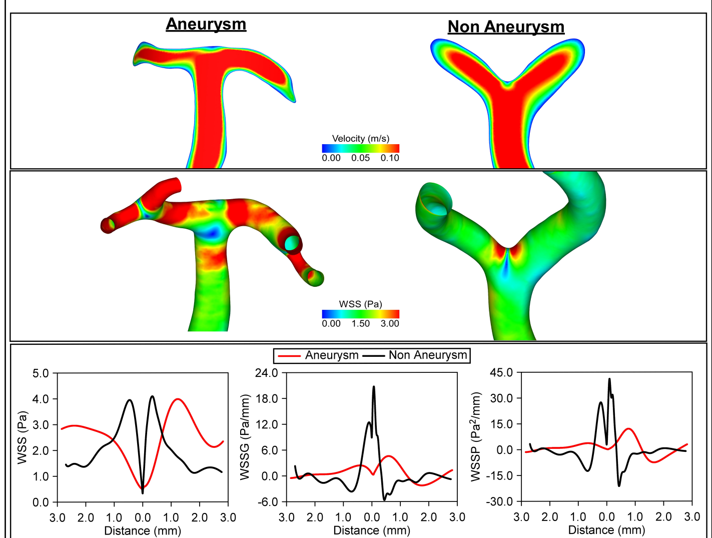
Results

Increased bifurcation angles led to increased RWSS and increased positive RWSSG. RWSS decreased distally from the apex in all models, but at a slower rate in wider bifurcations. Aneurysmal MCA bifurcations were characterized by a wider acceleration area (high WSS, high positive WSSG) compared to non-aneurysmal bifurcations. Bifurcations harboring aneurysms had significantly higher maximum RWSS (p=.01) and maximum RWSSG (p=.03) compared to control non-aneurysmal bifurcations. In addition, aneurysmal bifurcations had significantly higher RWSS (p=.01) and RWSSG (p=.03) compared to control non-aneurysmal bifurcations.

Conclusions

Aneurysm presence was correlated with higher RWSS and RWSSG at the apical region. RWSS was at maximum closer to the apex, fading distally from the point of flow separation, with slower flow convenience at wider angles. The higher RWSS at large angles adds a new dimension to the hemodynamic insult at the apical area by quantifying significant forces acting in multiple directions in the close proximity of the apex, distal into the daughter vessels, and outside of the medial pad protection. These previously undescribed hemodynamic shear stresses may trigger the destructive remodeling, previously associated with increasing WSS and positive WSSG, needed for aneurysm initiation.

Velocity and WSS distributions at MCA bifurcations



(A) Cross sectional velocity for a patient model with aneurysm removed (left) and a non-aneurysmal patient model (right). (B) WSS distribution for a patient model with aneurysm removed (left) and a non-aneurysmal patient model (right). (C) Plots of WSS, and WSS gradients across the apex for both the aneurysm removed model (red) and the non-aneurysm (black).

References

- Ingebrigtsen T, Morgan MK, Faulder K, Ingebrigtsen L, Sparr T, Schirmer H: Bifurcation geometry and the presence of cerebral artery aneurysms. J Neurosurg 101:108-113, 2004
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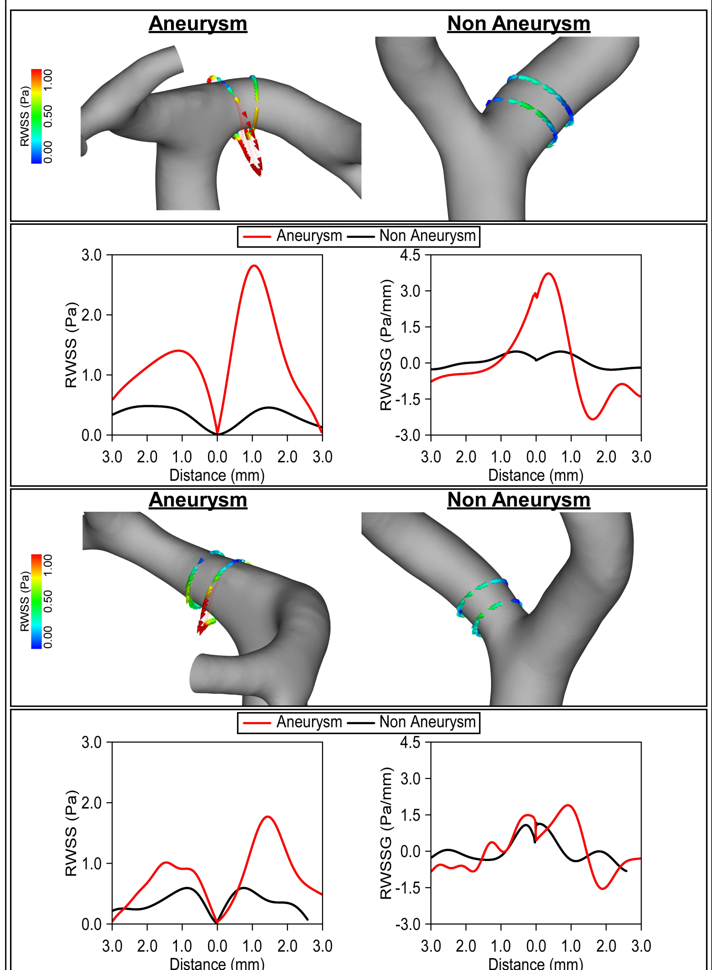
Rotational WSS



RWSS vectors, for aneurysmal and non-aneurysmal MCA bifurcations. Plots of RWSS and RWSS gradients at the most proximal cutting plane.