AANS/CNS Joint Cerebrovascular Annual Meeting
Los Angeles, California
February 15-16, 2016

Predicting Thrombus Formation in Patients with Internal Carotid Artery Webs

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Introduction

A 42 year-old male presented with a left middle cerebral artery stroke associated with an ICA web and only moderate stenosis. Although initially treated with medications, he later presented with recurrent strokes due to thrombus formation distal to the stenosis. In order to learn from this experience, patient-specific imaging information was combined with CFD analysis for predicting thrombus formation in the setting of carotid webs.

Goals

1.Conduct comparitive analysis of unhealthy and healthy carotid artery for the same patient.
2.Identify importance of CFD modeling for predicting future thrombus formation in order to avoid recurrent strokes.

Methods

1.3D volume rendering models were constructed for both ipsilateral and contralateral carotid artery using Scan IP(Simpleware Inc,V 7.0), exported to Fluent(Ansys Inc, V 15.0)
2.Mesh sensitivity analysis was conducted using 13 meshes to reveal stabilization of WSS for 3,366,134 tetrahedral elements-FIG 1
3.Unsteady time step analysis showed improved results with 0.0025 sec (400 steps)-FIG 2
4.Complete simulations were carried out for 4 cardiac cycles to dampen the transient effects

Mesh Sensitivity Analysis-Steady

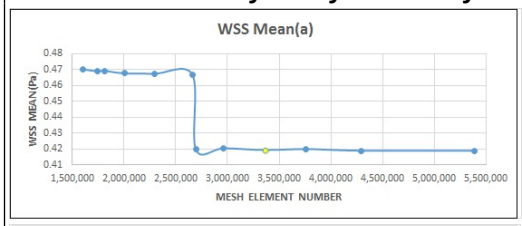

FIG 1(a)-WSS mean stabilization in ICA;
FIG 1(b)-WSS max stabilization in ICA

Time Step Analysis-Unsteady

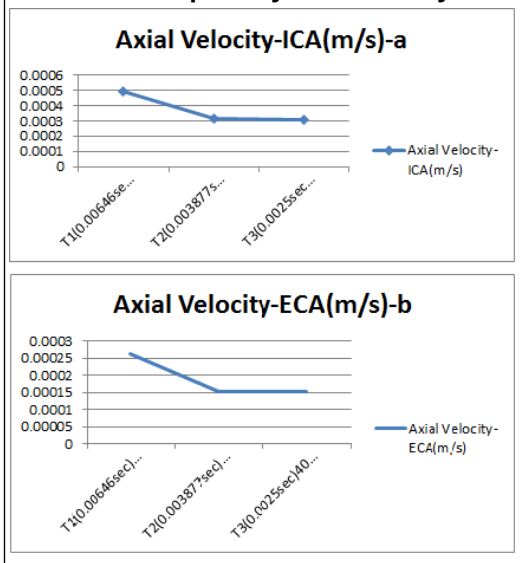

FIG 2(a)-Axial Velocity stabilization in ICA;
FIG 2(b)-Axial Velocity stabilization in ECA

Results

1.Low TAWSS values in the left carotid arise from sudden flow expansion behind the web which can be associated with wall thickening-FIG 3
2.OSI helps identify regions with reversed flow – elevated OSI values at site of the web confirms instantaneous WSS deviation from primary flow direction- FIG 4
3.RRT represents time spent by particles near the wall, which is directly proportional to chances of thrombus formation- FIG 5

Time Averaged Wall Shear Stress(TAWSS)

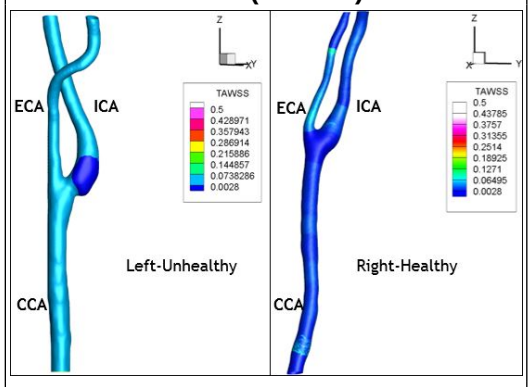

FIG 3- Low TAWSS distribution behind left carotid web

Oscialltory Shear Index (OSI)

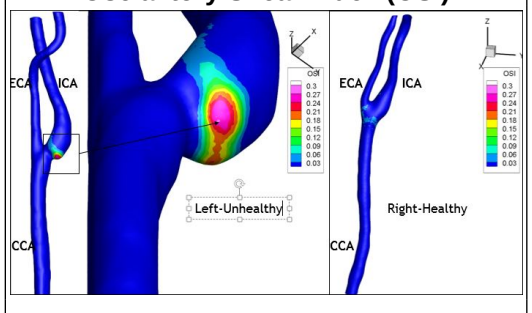

FIG 4-Higher distribtion of OSI presented at site of carotid web

Relative Residence Time(RRT)

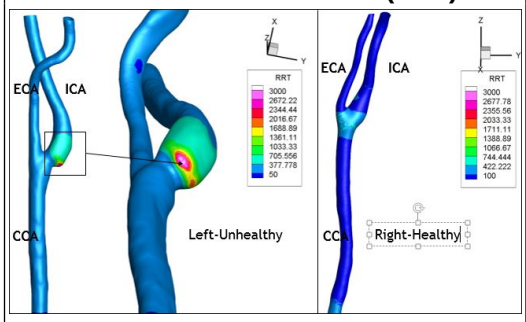

FIG 5- High distribution of RRT at site of left carotid web

Conclusions

The calculated hemodynamic parameters (TAWSS, OSI, and RRT) have been previously associated with thrombus formation and stroke(1,2). CFD may yield potentially important clinical information regarding the risk of thrombus formation in the setting of carotid webs. However, additional patients and prospective studies are required to validate these findings.

References

1.Arab-Ghanbari M, Khani M, Arefmanesh A, et al. Analysis of Blood Turbulent Flow in Carotid Artery Including the Effects of Mural Thrombosis Using Finite Element Modeling. American Journal of Applied Sciences. 2009;6(2):337.
2.Rayz VL, Boussel L, Ge L, et al. Flow residence time and regions of intraluminal thrombus deposition in intracranial aneurysms. Annals of biomedical engineering. 2010;38(10):3058-69.

Abbreviations

CFD-Computational Fluid Dynamics, CCA-Common Carotid Artery, ICA-Internal Carotid Artery, ECA-External Carotid Artery, WSS-Wall Shear Stress.