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A 3D Computational Model of the Hemodynamic Changes in EC-IC Bypass with Physiologic Boundary Conditions

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Introduction

Intracranial arterial stenosis (IAS) accounts for about 10% of all ischemic strokes and has a recurrence rate as high as 25% in some poulations. The EC-IC Bypass Trial failed to demonstrate the benefit of a superficial temporal artery (STA) to middle cerebral artery (MCA) bypass over medical management, particularly for patients with severe stenosis rather than occlusion. These outcomes could be explained by retrograde flow from the bypass competing with flow from the stenosis, creating conditions at risk for thrombosis and the development of thrombolic emboli, such as stagnant or turbulent flow.

Computational flow dynamics (CFD) models of small -caliber intracranial vessels with complex geometry have been limited by the resolution of current imaging techniques. In previous studies modeling the hemodynamics of IAS we have overcome this limitation by extracting the vascular anatomy from a biplane angiogram and adding anatomical details. We present an extension of this work in which we reconstructed the vascular geometry of a patient with an EC-IC bypass to demonstrate the hemodynamic effects of this treatment at varying degrees of stenosis.

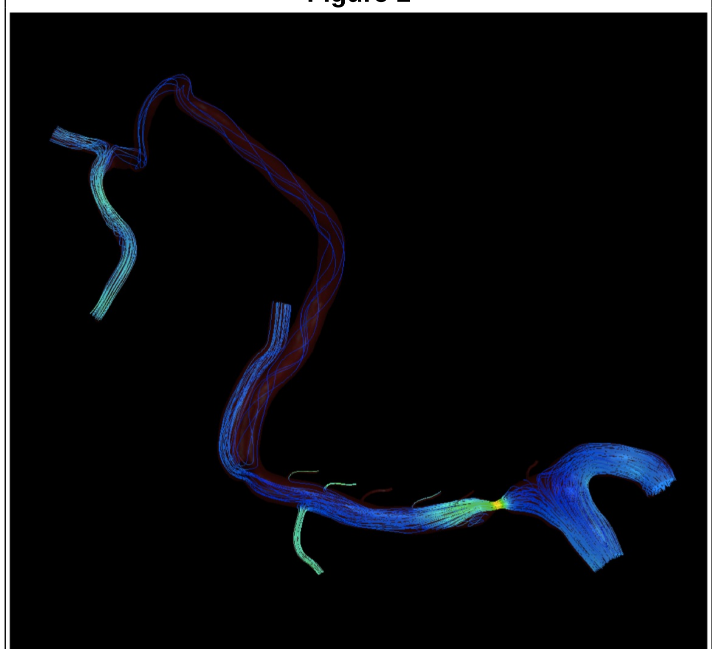
Methods

The model was constructed from the biplane angiogram of a patient after STA-MCA bypass using 2D-to-3D reconstruction of semi-automatically delineated vessel branches. The anterior temporal branch and the lenticulostriates (LSAs) were added based on the descriptions by Djulejic et al. The model was modified with varying degrees of stenosis. The boundary conditions of the model outlets were adjusted to account for the autoregulation of the cerebral vasculature based on the steady state resistance of a 1D model with autoregulatory outlets (Ursino and Lodi) (**Table 1**). The ANSYS Simulation Technology package was used to evaluate hemodynamic parameters at 70% and 90% stenosis. Flow simulations assumed a rigid wall, Newtonian blood flow at a flow rate of 5g/s

Results

The 70% stenosis showed small pressure drop across the stenosis compared to the 90% stenosis (712Pa, 3618Pa). Flow velocity and wall shear stress (WSS) were substantially higher in the M1 segment distal to the lesion in the 70% stenosis model than in the 90% model (105cm/s, 27cm/s; 3.4Pa vs. 0.66Pa). Both models exhibited slow retrograde flow through the M2 segment (7cm/s, 10cm/s). Maximal turbulent kinetic energy (TKE) was higher in 70% stenosis model (0.00586m^2/s^2, 0.0012m^2/s^2).

Figure 1



Velocity streamlines of in an artery with 70% stenosis

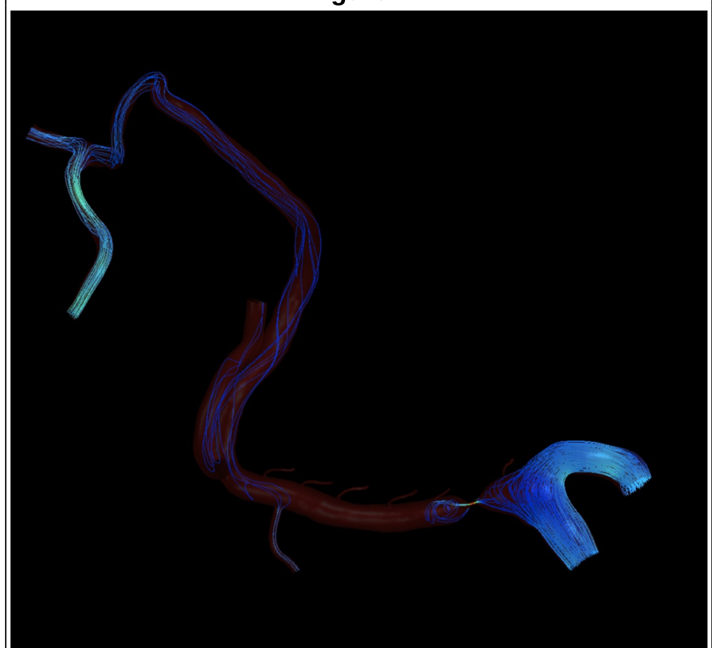
Table 1

(mmHg)	ACA	ATA	MCA 1	MCA 2	LSA 1	LSA 2-6
70%	92.7	81.6	85.5	86.7	90.0	83.0
90%	89.2	63.0	63.9	65.2	90.0	60.0

Conclusions

EC-IC bypass causes competitive flow within the M1 and M2 segments resulting in near complete stagnation of flow in regions of the MCA with high WSS and TKE, a set of conditions at high risk for intra-arterial thrombosis.

Figure 2



Velocity streaminlines in an artery with 90% stenosis

References

Ursino, M. and Lodi, C.A. **A simple mathematical model of the interactions between intracranial pressure and cerebral hemodynamics**. *Journal of Applied Physiology*. 1997

Djulejic, V., Marinkovic, S., et al. **Morphometric analysis, region of supply and microanatomy of the lenticulostriate arteries and their clinical significance**. *Journal of Clinical Neuroscience*. 2012