COMPARISON OF FLOW AND WALL-SHEAR STRESS USING 4D FLOW MRI AND CFD IN CAROTID PHANTOMS WITH DIFFERENT STENOSIS LEVELS

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1. Introduction

Internal carotid artery (ICA) stenoses are a major source of stroke [1]. Accurate assessment of the hemodynamic features is essential for enhancing diagnostic and therapeutic strategies in carotid artery diseases.

2. Materials and Methods

A patient-specific geometry was used as baseline and modified using the NASCET methodology [2] to represent ICA stenoses at three levels: 0% (healthy) and 80% (severe). The silicone phantoms were perfused at a steady flow rate corresponding to peak systolic flow (~13 ml/s) in the common carotid artery (CCA), and the flow field was captured by a 7T scanner (Siemens MAGNETOM) with an isotropic spatial resolution of 0.5 mm. Results were compared to CFD simulations conducted in OpenFOAM employing a verified laminar flow approach with an extremely refined mesh (maximum cell size 0.075 mm), which served as the ground truth for flow within the phantom models.

3. Results

The 4D flow MRI effectively captured post-stenotic flow features, emphasizing jet formation at the stenosis and the generated vortices. Quantitatively, on a plane positioned after the stenosis, where complex flow patterns are anticipated, MRI underestimated the peak velocity by 21%, a deviation primarily related to its low spatial resolution and voxel averaging. In the bifurcation region, the average wall shear stress (WSS) magnitudes for the healthy case are 0.398 Pa (CFD) and 0.326 Pa (MRI), and for the severely stenosed case, they are 0.793 Pa (CFD) and 0.493 Pa (MRI), respectively.

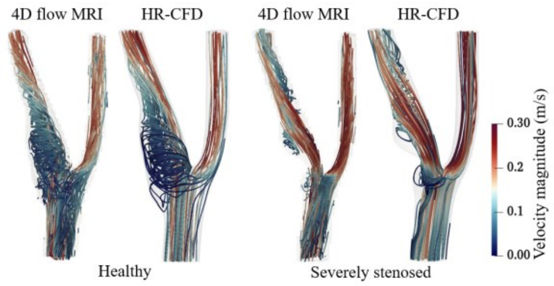

Figure 1: 3D Streamlines from MRI and CFD

4. Discussion and Conclusions

4D flow MRI effectively determines flow patterns but faces challenges in quantifying secondary flows and recirculation regions. The discrepancies between 4D flow MRI and CFD become more pronounced with increasing flow complexity. Despite these challenges, there is a reasonable degree of similarity in velocity and WSS distributions between the two methods, though the agreement on WSS magnitudes diminishes as WSS values increase. This underlines the efficacy of CFD in analyzing complex flows and the complementary contribution of 4D flow MRI to hemodynamic research.

5. References

1. Lui, Mattia, et al. "On the turbulence modeling of blood flow in a stenotic vessel." Journal of biomechanical engineering 142.1 (2020).
2. Ferguson, Gary G., et al. "The North American symptomatic carotid endarterectomy trial: surgical results in 1415 patients." Stroke 30.9 (1999): 1751-1758.

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