Accuracy and Reproducibility of CFD Applied to Contrast-enhanced 2D TOF MR Images of a Stenosed Carotid Artery Phantom

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INTRODUCTION

Computational Fluid Dynamics (CFD) is a valuable technique for the estimation of complex blood flow in vivo, but requires accurate arterial geometry. Magnetic Resonance Imaging (MRI) is widely used for CFD, but complex flows in stenosed arteries may cause signal loss which may compromise the accuracy of MRI (Moore, 1999). This study investigates the accuracy and reproducibility of geometric and flow parameters determined by CFD applied to MRI images of a stenosed carotid artery bifurcation phantom under physiologically realistic flow conditions.

METHOD

An anthropomorphic phantom of a carotid artery bifurcation consisting of common (CCA), internal (ICA) and external (ECA) segments was scanned twice using contrast-enhanced 2D time-of-flight (TOF) MRI during perfusion with a blood-mimicking fluid (water-glycerol-gadolinium mix) using a physiological flow waveform. The ICA had an asymmetric 70% diameter stenosis. For each scan geometry was reconstructed using in-house software and CFD modeling was performed with CFX-4 using the same inlet velocity boundary condition measured by Doppler ultrasound. Lumen area, % tortuosity ((1- shortest vessel length/measured length) x 100) and time averaged wall shear stress (WSS) by CFD were compared between MRI scans and between pooled MRI data and computer-aided design (CAD) specified geometry of the phantom, and analysed as described by Bland and Altman (Bland, 1999).

RESULTS

Reproducibility and phantom comparison data are shown in table 1. The root mean square error in cross-sectional area expressed as % of average CAD cross-sectional area between MRI and CAD was 5% in CCA, 18% in ICA and 10% in ECA. The maximum difference in the area of the ICA was 9.1mm^2 (29% underestimate by MRI). This was seen 12mm superior to the bifurcation. This location corresponded to the region of post-stenotic dilatation and may be attributable to signal loss in regions of complex flow. Estimates of tortuosity between scans and between scans and CAD were very similar. Tortuosity ranges from 0 to over 30%. The true tortuosity of the CAD was 0.63% (CCA), 4.6% (ICA), 1.7% (ECA). The difference in tortuosity between CAD and scan 1 was 0.52% (CCA), -2.39% (ICA) and –0.53% (ECA) and for scan 2 was 0.44% (CCA), -1.54% (ICA) and –0.6% (ECA).A comparison of WSS between the three models is shown (*Figure 1*). In general, wall shear stress is underestimated at the throat of the stenosis, but overestimated in the post-stenotic region of the ICA.

FIGURE AND TABLE

	CCA (mm^2)	ICA (mm^2)	ECA (mm^2)
Scan 1 vs. Scan 2	3.9±3.6	1.5±4.1	-0.4±1.3
Scan vs. CAD	-1.7±2.2	3.4±4.1	-0.7±1.7

Table 1: Mean difference ± standard deviation of the differences between models built from scans and CAD.

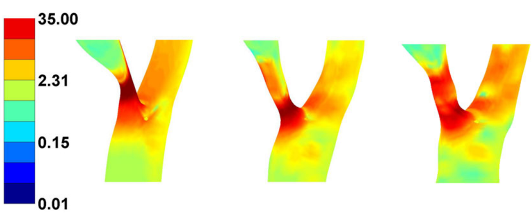

Figure 1: WSS distribution (N/m^2) in models built from CAD (left), scan 1(middle) and scan 2 (right).

CONCLUSION

Overall, reproducibility of geometry between MRI scans and comparison with CAD is good although there is some loss of accuracy in the post-stenotic region. Comparison of WSS using physiological flow conditions showed good qualitative agreement between MRI and CAD.

REFERENCES

Bland JM, Altman DG, Stat Methods Med Res 8: 135-160, 1999.
Moore JA, *et al*, Ann Biomed Eng 27: 32-41, 1999.