MRI-BASED COMPUTATIONS OF FLOW FOLLOWING ENDOVASCULAR INTERVENTIONS

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Introduction

Time-resolved phase-contrast MR velocimetry (4D MRV) is capable of measuring three-dimensional velocity fields in blood vessels. Hemodynamic descriptors affecting disease progression and vessel remodeling can be evaluated using these *in vivo* measurements, as well as by constructing image-based computational fluid dynamics (CFD) models. Despite the increasing accuracy of the 4D MRV methods, CFD still offers advantages in that it allows one to simulate flow fields resulting from vascular and endovascular interventions prior to the actual procedure. Postoperative flow simulations can help assess hemodynamic changes caused by various interventions and thus avoid unfavorable flow conditions following a treatment. In this study CFD models based on preoperative MRA and MRV were used to predict postoperative flows in 3 intracranial aneurysms considered for flow-diverter stent (FDS) placement. The fine struts of the FDS device create resistance to the flow across its wall, thus reducing the flow into the aneurismal sac and promoting its thrombotic occlusion.

Methods

High-resolution, CE-MRA data were used to obtain preoperative vascular geometries for 3 giant ICA aneurysms. Numerical simulations of the preoperative and postoperative flow were carried out with a finite-volume solver, FLUENT. Preoperative flow simulations were compared to 4D MRV data to ensure the model adequately represented the flow field. In order to conduct CFD simulations of the postoperative flow, the geometries were modified by adding a thin porous tube to model FDS. In one case, a silicone flow phantom of the aneurysmal ICA was constructed and the UCSF neuro-interventional team deployed an FDS in this model. The postoperative flows predicted with CFD simulations were compared to either *in vivo* 4D MRV measurements conducted following the procedure, or to *in vitro* 4D MRV measurements obtained in the stented phantom.

Results

For the first patient, a comparison of the preoperative flow measured *in vivo* with 4D MRV (Fig 1a) and computed with CFD (Fig 1b) shows a remarkable similarity. The CFD-predicted flow following the FDS placement is shown in Fig 1c. The procedure is expected to cause most of the flow to go through the FDS, however a substantial fraction of the flow is likely to leak through the proximal part of the device. This could possibly be amended by deploying an additional stent inside the original one (in a telescoping, or nested fashion) in order to increase hemodynamic resistance.

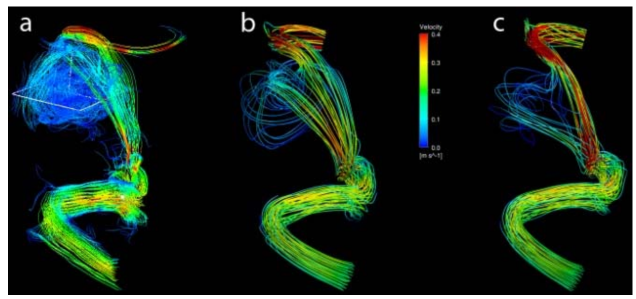

Figure 1 Preoperative streamlines in giant ICA aneurysm obtained with (a) in vivo PC-MRI, (b) CFD. Streamlines following FDS placement predicted with CFD (c).

In the second case, the preoperative flow was characterized by a high-velocity jet propagating across the aneurysm, as shown in Fig. 2 (a). The CFD-predicted flow following the FDS placement (Fig. 2b) was compared to 4D MRV measurements conducted in a stented flow phantom (Fig 2c). The procedure resulted in eliminating the high-velocity jet and channeling the flow into the distal ICA. A small fraction of the flow passes through the stent, however the velocities are very low everywhere in the aneurysmal sac. There is very good qualitative agreement between CFD predictions of post-procedural flow and the 4D MRV data.

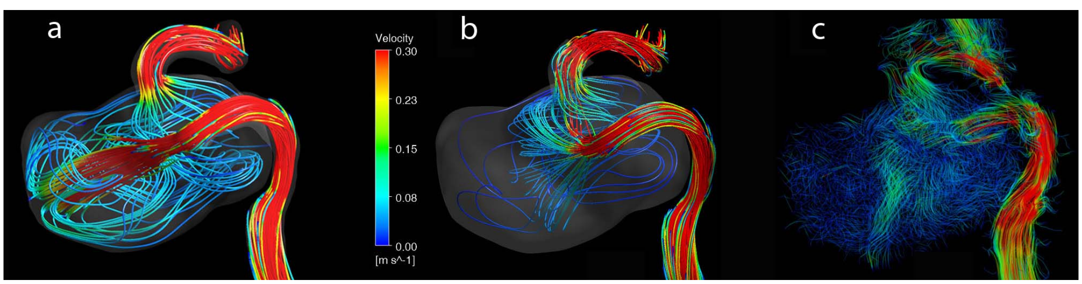

Figure 2 Preoperative streamlines in a giant ICA aneurysm computed with CFD (a). Streamlines following FDS deployment obtained with CFD (b) and with in vitro 4D MRV (c).

For the third patient, the flow field following the FDS placement was measured with 4D MRV *in vivo*. The flow field predicted with a computational model including the FDS geometry is shown in Fig. 2 (a). The MRV-measured postoperative flow is shown in Fig. 2(b). In each approach the results show that most of the flow propagates inside the FDS, while there is still some leak through the walls, forming a large vortex in the aneurysm. The low postoperative velocities in the aneurysm are likely to induce its thrombotic occlusion.

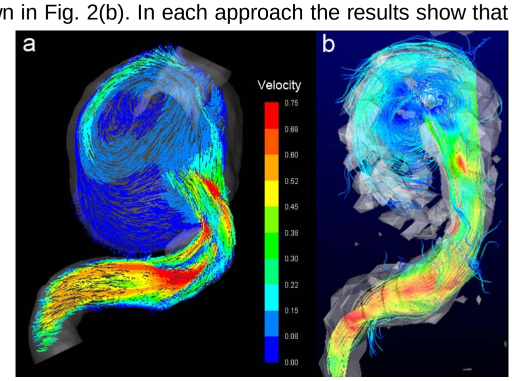

Figure 3 Flow in a giant ICA aneurysm following FDS placement (a) predicted with CFD and (b) measured with in vivo 4D MRV.

Conclusions

The results indicate that MRI-based CFD models can be used to predict postoperative flow fields on patient-specific basis.

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