PC-MRI VELOCIMETRY AS IMPROVED INITIAL APPROXIMATION IN ITERATIVE CFD MODELING

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Introduction

Phase-contrast magnetic resonance velocimetry (PC-MRV) is capable of measuring blood flow in vivo, providing time-resolved 3D velocity fields. While this method provides flow data at the time of the imaging study, its limited spatial resolution, particularly in near-wall regions, can lead to errors in estimation of wall shear stress (WSS) – an important hemodynamic descriptor that is related to vascular disease progression. An accurate estimation of WSS can be obtained with patient-specific CFD models with refined meshes, constructed from MR angiography and velocimetry data. However, CFD simulations on refined meshes typically require significant computation times to attain convergence of the iterative numerical solution of the governing flow equations. In this study we investigated whether it is possible to reduce computational time to convergence by using measured PC-MRV data as an initial guess for the iterative solution, rather than starting the simulation from zero values, as it is conventionally done. The hope was that by combining in vivo measurements with computational modeling it would be possible to benefit both techniques and quickly obtain accurate WSS estimations.

Methods

High-resolution (0.6 x 0.63 x 1.2 mm) CE-MRA data were acquired for three basilar aneurysm patients and used to obtain luminal geometries for computational modeling. Velocity components obtained with PC-MRV for these patients were used to prescribe the initial conditions (IC) throughout the volume of the computational models. Relatively low-resolution MR data was interpolated on a higher-resolution computational mesh. The flow boundary conditions at the inlet vessels were also prescribed from PC-MRV measurements in transverse planes. Numerical solution of the pressure equation takes longer than that for the momentum equation; thus in order to reduce computational time, a rough estimate of the initial pressure field was obtained for each patient from the available MRV data by using Bernoulli's equation and a hydrostatic head. The flow fields predicted by CFD with zero IC were compared to those determined using MRV IC after the same number of iterations. In order to obtain quantitative comparison, an area of the aneurysmal wall where WSS values were less than a threshold (0.25 Pa) was calculated in each simulation run. Our previous studies suggested that aneurysmal growth is more likely to occur in such areas of low WSS.

Results

The flow and WSS fields obtained for all patients in simulations with IC provided by PC-MRV matched the flow and WSS fields computed with zero IC. The flow vectors obtained for one of the patients with 3D PC-MRV technique are shown in Figure 1 (a). The CFD results showing flow streamlines and WSS distribution obtained in simulations with IC provided by MRV are shown in Figure 1 (b) and (c). In all cases, providing the velocity and pressure distribution at the initial step resulted in a rapid decrease of the residuals in the beginning of the iterative process, but later in the simulation the rate of convergence decreased and became similar to that of a simulation with zero IC. While the time required to reach full convergence remained comparable to the zero IC case, there was a noticeable decrease in time taken by the solver to get within 10% of the converged solution. The remainder of the iterative time was necessary to decrease pressure residuals.

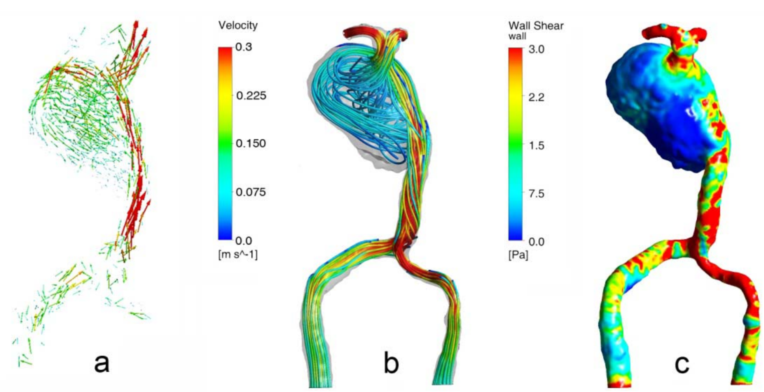

Figure 1 (a) Velocity vectors obtained with 3D PC-MRV technique; (b) flow streamlines obtained with CFD; (c) WSS distribution obtained with CFD.

For each patient, the low WSS area predictions were calculated at different number of iterations in both zero IC and MRV IC cases. The WSS area obtained from the fully converged run with zero IC was assumed to be the best estimation. A percentage error was then calculated for the low WSS area predictions obtained at different number of iterations for zero IC as well as at the same number of iterations for MRV IC. These errors were plotted as a function of computational time (Figure 2). The results show that in all cases, the reduction in computational time was as great as 25%. While this is a positive result, it should be noted that additional time was required to obtain and prescribe the IC from the 3D MRV data. Thus, the overall advantage of this method is limited. A more promising method of reducing computational time is in employing numerical schemes with faster rates of convergence.

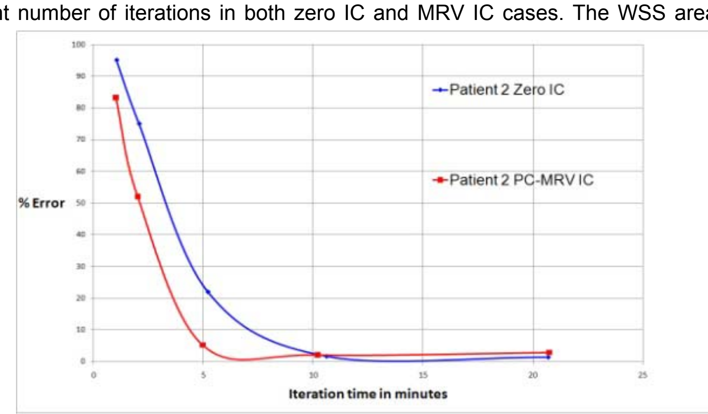

Figure 2 Limited gain in computational time for CFD simulations with initial guess from MRV measurements.

Conclusions

PC-MRV measurements were used to prescribe initial conditions for CFD simulations in patient-specific models. The flow fields obtained with CFD corresponded to MRV measurements and computational time required to reach convergence was reduced by up to 25%. This limited gain demonstrated that the proposed technique of combining PC-MRI and CFD modeling is not optimal.

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