Modeling Blood Flow for Improved Evaluation of Atherosclerotic Disease

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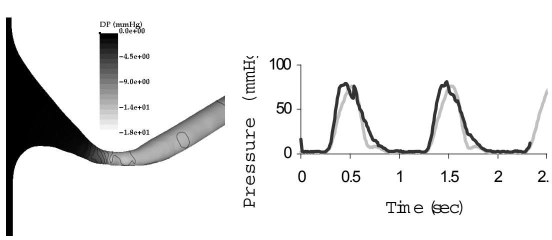
Purpose: Atherosclerotic disease is defined by a progressive narrowing of the arteries due to the growth of plaques within the arterial walls. Ultimately, atherosclerotic disease leads to ischemia or infarction due to simple obstruction of the blood flow from the plaque itself or by the production of emboli that obstruct downstream vessels. The obstructive effect of plaque is considered most important for assessment of atherosclerotic disease of the renal arteries whereas the risk of plaques producing emboli is considered more important in assessing in carotid artery disease. In current practice, all arteries are assessed according to the degree of stenosis that is only indirectly related to the obstructive effect of the plaque and the risk of producing emboli. More effective methods for evaluation of atherosclerotic disease may be obtained by considering the functional significance of the stenosis (pressure gradient) and by considering the mechanical stresses on the wall of the vessel (wall shear stress) that may lead to the production of emboli.

Methods: Methodology has been developed that allows for assessment of hemodynamic features such as pressure gradients and wall shear stress in a non-invasive manner using realistic computational fluid dynamics (CFD) models that incorporates magnetic resonance angiography (MRA) and phase-contrast magnetic resonance (PC MR) imaging. In this methodology, to be referred to as vascular CFD, finite-element models, governed by the incompressible, time-dependent Navier-Stokes equations, are constructed from the imaging in a nearly automated manner. Currently, simplifying assumptions are incorporated including the rigidity of the vessel wall and Newtonian behavior of the blood. This methodology has been quantitatively validated in realistic physical flow-through models and *in vivo* in carotid arteries from normal subjects.

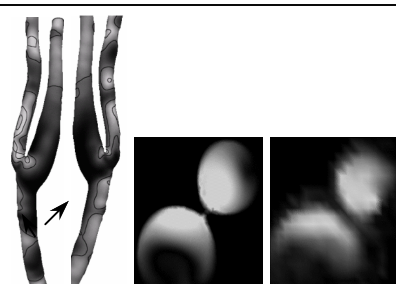
Results: Vascular CFD has been found to be reliable in studies with physical flow through models (one comparison shown in figure 1) and in carotid arteries in normal subjects (results for one subject shown in figure 2).

Conclusion: Vascular CFD has demonstrated promise for improving the evaluation of atherosclerotic disease. Studies are underway to assess the accuracy of vascular CFD *in vivo* and to establish the value vascular CFD in clinical practice.



a b

Figure 1. *Validation of pressure-gradient measurements by vascular CFD in physical flow-through model. Distribution of relative pressures in the vicinity of the stenosis (a). The pressure gradient by vascular CFD (dark line) is compared with direct transducer measurements (gray line)(b).*



a b c d

Figure 2. *Vascular CFD in carotid arteries of normal subject. Mean wall shear stress (MWSS) distribution (a)(b). Low MWSS in bifurcation region (arrowheads) as predicated by idealistic models. Comparison of velocity profiles at intermediate location from vascular CFD (c) with direct measurement by PC MR (d).*