Patient-Specific Wall Shear Stress Determination in the Coronary Arteries Using Phase Contrast Magnetic Resonance

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Introduction: Low and oscillatory arterial wall shear stress (WSS) have been shown to have an effect on many factors implicated in atherosclerotic lesion development. The majority of studies on the relationship between low or oscillating WSS and sites of intimal thickening and early atherosclerotic lesion development are based on *in-vitro* model studies of flow and WSS distribution. These models are based on *average* vessel geometries with *average* flow conditions and compared to *average* pathology distribution of lesions that may obscure the true relationship between WSS and lesion distribution[1]. Recent techniques have been developed using coronary MR angiography to create patient-specific 3D models along with velocity measurements of blood flow using phase contrast magnetic resonance (PCMR). However, these models may lack adequate spatial resolution for accurate, localized calculation of WSS[2]. The purpose of this study was to determine *patient-specific* WSS in the proximal coronary arteries using a combination of PCMR, computed tomography coronary angiography (CTCA), and computational fluid dynamics (CFD) to study patient-specific hemodynamics of the left coronary artery bifurcation.

Methods: A detailed 3D geometry and time-varying flow at the inlet of the model are required to solve the complete flow field and calculate WSS through the coronary arteries using CFD. The geometry data for creating patient-specific CFD models of the coronary arteries came from an ECG-gated, 64-slice CTCA scan. Coronary arteries were segmented using the CardIQ image processing platform (GE Healthcare). Contours of the vessel lumen for the left main, left anterior descending, and left circumflex coronary arteries (LM, LAD, LCX) were segmented at 2mm increments along the artery centerline. This data was exported to a program that constructs the geometry and mesh used for CFD simulation (GAMBIT, Fluent Inc., Lebanon, NH). Faces are wrapped around the circular "ribs" defined by the CT reconstruction to form the vessel surface and a tetrahedral mesh is generated in the enclosed volume.

Time-varying velocity curves were determined by a segmented PCMR scan using both navigator-echo gating and prospective ECG-gating. The sequence was a segmented FLASH sequence (3 lines/segment), with flow encoded and non-encoded images separated by the heartbeat. Other imaging parameters were: 256mm^2 FOV, 4mm slice thickness, 256 matrix, TR/TE/flip = 7.0/3.5/15, and the through-plane velocity encoded value was set to 35cm/s. MR velocity measurements were taken at the proximal left main coronary artery (LM) and the proximal left anterior descending artery (LAD). Time resolved velocity of blood flow in the LM was used as an inlet boundary condition for the CFD model while measurements of velocity in the LAD were used to weight the flow division between the LAD and LCX. Computations were performed with a commercial CFD code (Fluent, Fluent Inc., Lebanon, NH) assuming Newtonian, incompressible, and laminar flow. Distributions of WSS were analyzed in the LM and the proximal regions of the LAD and LCX.

Results: Two normal subjects and one patient have been studied. Both time-resolved and time-averaged WSS distributions were calculated. Localized areas of lower WSS were observed along the outer walls of the LAD and LCX just distal to the LM bifurcation. This location has been identified in pathology studies to have a high incidence of atherosclerotic lesions.[3]

Conclusions: A technique has been developed to evaluate patient-specific hemodynamics and WSS distributions in the coronary arteries using a combination of PCMR, CT coronary angiography, and computational fluid dynamics. This technique could be useful for future *in vivo* correlation studies of arterial hemodynamics and vessel wall morphology in combination with intravascular ultrasound.

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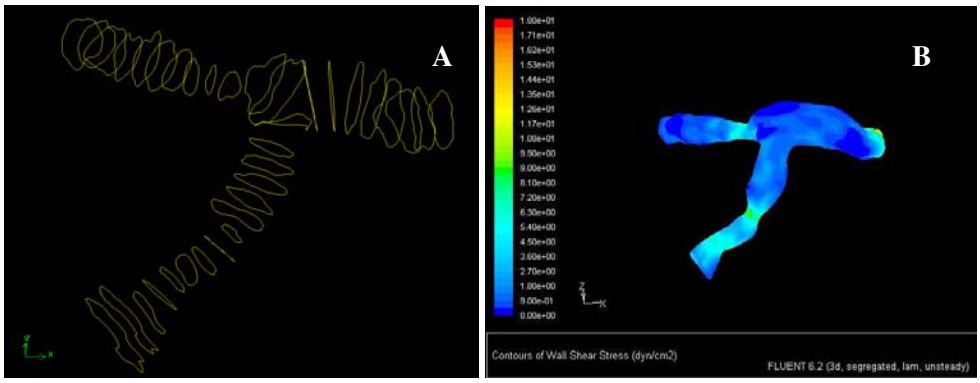
3. Glagov, S., et al., Arch Pathol Lab Med, 1988. **112**(10): p. 1018-31.



Figures showing: (**A**) "ribs" of the LM, LAD, and LCX as determined by CTCA and (**B**) WSS contours along the vessel wall for one cardiac phase calculated by CFD analysis using PCMR velocity measurements as boundary conditions.