Coronary Blood Flow Measurement Using 3.0T Phase Contrast Magnetic Resonance

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INTRODUCTION: Measuring blood flow in the major coronary arteries has clinical significance for assessing coronary perfusion reserve or quantitatively evaluating regions with poor and normal perfusion. Basic science applications for coronary flow measurements include providing boundary conditions for computer simulations of localized hemodynamics[1]. Although phase-contrast magnetic resonance (PCMR) imaging is a well-established technique for measuring fluid velocity in large vessels, respiratory and heart motion and small size of the coronary arteries has limited the routine use of PCMR. 3.0T has the potential to increase signal-to-noise ratio for PCMR measurements in small vessels.

PURPOSE: (1) To evaluate the accuracy of navigator-echo gated, 3.0T phase velocity mapping (PVM) in a small diameter, *in vitro* study with flow rates and respiratory motion representative of the coronary arteries, and (2) to obtain *in vivo* measurements of coronary blood flow in the left anterior descending (LAD), left circumflex (LCX), and right (RCA) coronary arteries in human volunteers.

METHODS: All scans were performed on a Philips Intera 3.0T equipped with a 6-element cardiac phased array coil. A programmable flow pump (CardioFlow 1000, Shelley Medical Systems, Toronto, Canada) was used to generate steady, laminar flow at a range of velocities typical of coronary flow through noncompliant plastic tubing with an inner diameter of 4mm. Respiratory motion was simulated using an inflatable bladder and an animal respirator with a frequency of 10 cycles/minute and excursion of 15-20mm. A navigator-echo gated, PVM scan was positioned perpendicular to the flow phantom. The sequence was a segmented FLASH sequence (3 lines/segment), with flow encoded and non-encoded images separated by the heartbeat to maximize acquired phases. 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 encoding value was set to 40cm/s. A physiology simulator was used for ECG triggering at 60bpm to acquire 18 simulated phases. A leading navigator pulse was used. Velocity measurements were evaluated using the FLOW software package (Medis, Lieden, The Netherlands). Regions-of-interest were drawn individually for each vessel cross-section using the magnitude phase-contrast images and then copied to the velocity encoded images. Flow values were compared to timed collections.

The same PVM sequence was used to measure coronary blood flow in a total of 16 coronary vessels (6 RCA, 6 LAD, 4 LCX) in nine individuals. Localization of the coronary arteries and orientation of the flow scan plane were done using a series of navigator-echo gated 3D coronary MRA sequences (segmented FLASH, 270mm^2 FOV, 256matrix, TR/TE/flip = 3.8/1.9/20, 2mm slice thickness, 15-25 lines/segment centrically acquired, spectral fat saturation, T2-prep, SENSE reduction factor = 2, prospective ECG-gating). Acquisition of the MRA scans was delayed to mid to late diastole, depending on quiescent period noted on transverse cine slice (50 phases). The navigator-echo gated PVM scan was planned perpendicular to the vessels approximately 4cm from the coronary ostia – distal to the left bifurcation but before other branches in the LAD and LCX. For *in vivo* scans, scan parameters were the same as the phantom study except the velocity encoding value was reduced to 30cm/s. The sequence acquired 10-19 cardiac phases depending on the heart rate. Velocity measurements were evaluated as described previously. Both the average velocity, peak velocity, and flow rate were measured in all arteries, and assessed in terms of inter-subject variance and known coronary flow rates.

RESULTS: The phantom studies showed that flow measurements using navigator-echo gated PVM at 3.0T were accurate within 15% of the known flow rates.

Clear images of coronary arteries were obtained in all volunteers, as shown in one volunteer (Figure 1). Coronary velocity was measurable in 224/243 total phases (92%). An example cross-sectional RCA flow image is shown in Figure 2, along with a sample velocity curve. Average peak velocity over all subjects was 11.9±6.4cm/s in the RCA, 13.6±6.9cm/s in the LAD, and 13.6±4.4cm/s in the LCX. These measurements are within previously observed velocity values for coronary blood flow[2, 3].

CONCLUSION: We have shown that navigator-echo gated, phase velocity mapping of coronary flow is feasible at 3.0T and accurate to a clinically acceptable level. We present time-resolved, average velocity curves in the RCA, LAD, and LCX for a sample of healthy volunteers which can be used for computational fluid dynamics (CFD) simulations of coronary flow.

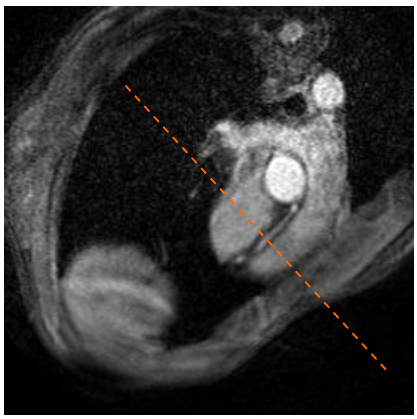

Figure 1. 3-point-plan image of a right coronary artery is shown with the slice plane used for a subsequent PVM scan.

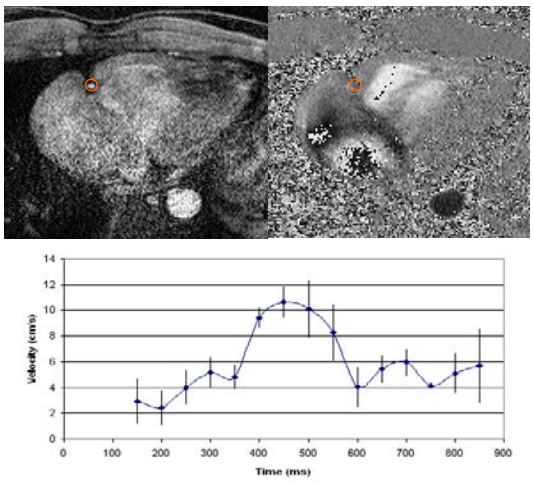

Figure 2. Cross-sectional modulus and phase images from an RCA PVM scan with average RCA velocity curve over all subjects.

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