Simultaneous Evaluation of Blood and Tissue Velocities From Single VENC Phase-contrast MR Imaging

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Background: Trans-mitral blood flow and mitral annular velocity profiles are routinely assessed during echocardiography-based assessments to provide for the grading of diastolic dysfunction and estimation of left atrial pressures [1]. While these measures may similarly be obtained by phase contrast MRI, each requires a separate acquisition (using different velocity encoding (VENC) values) and subsequent analysis to accommodate for the vastly different velocities [2]. Previous attempts to simultaneously quantify blood flow and wall-motion suggested that unwrapping of phase data within the cardiac blood pool cannot be accomplished using a single VENC acquisition when the VENC is ≤ 40 cm/s [3,4]. Here we offer a unique approach, utilizing a novel phase unwrapping algorithm, to achieve simultaneous evaluation of tissue and blood-flow velocities from a single low-VENC image dataset.

Methods: Cardiac MR imaging was performed using a 3.0-T whole-body scanner (MR 750, GE) in three volunteers. Through-plane phase-contrast (velocity-encoded) images were acquired in the short-axis plane at the level of the mitral annulus using a retrospectively triggered 2D fast cine phase contrast pulse sequence (segmented k-space gradient-echo; 7.3/4.4 ms TR/TE; 15° flip angle, 8-mm slice thickness, 40 cm/s VENC, 4 lines per segment, 30 phases reconstructed) with first-order flow compensation in all dimensions to minimize artifacts from flow and motion. All images were analyzed off-line using algorithms developed within MATLAB. Phase unwrapping of velocity data was achieved using a recursive orthogonal referring approach (PUROR) that removes streaks resulting from conventional 2D phase unwrapping (details in manuscript under review in MRM). For this application, unwrapping was performed in three-dimensions (with time during the cardiac cycle being the 3rd dimension).

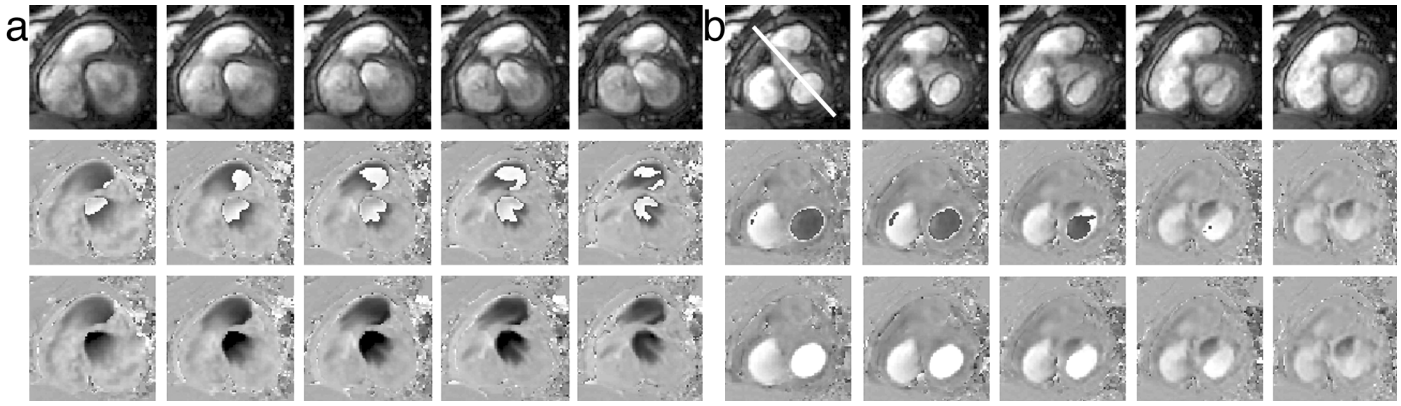

Figure 1. Representative magnitude (top), measured (mid) and unwrapped phase (bottom) images selected from the 30 frames and representing the systolic (a) and early filling (b) stages (images are separated by 25 ms.). The line in (b) is the line for which the M-mode data and velocities are presented in Fig. 2.

Results: Example phase-contrast images corresponding to mid systolic and early diastolic cardiac phases are shown in Fig. 1a and 1b, respectively. Phase aliasing is clearly seen within the LV and RV blood pool (middle row in Fig. 1a and 1b). Following application of the PUROR algorithm these images were successfully unwrapped (bottom row in Fig. 1a and 1b). Figure 2a shows a representative phase-contrast M-mode MRI image [5] at the mitral annulus, with velocities encoded in colour. Blood-flow velocities during mid-systolic ejection (S), early-diastolic filling (E) and during the atrial contraction of late diastole (A) can be easily identified from Fig. 2a and are plotted in Fig. 2b. The single-VENC acquisition has enabled determination of peak velocity parameters within the blood pool (S = -74.6, E = 64.5, and A = 43.3 cm/s) and of the mitral annulus (S' = 10.3, E' = -10.6, and A' = -7.6 cm/s). Phase unwrapping over the entire cardiac cycle was accomplished in 0.5 seconds per slice, using the PUROR approach implemented in MATLAB.

Discussion: Post-processing of phase-contrast M-mode MR images using the described PUROR approach allows for simultaneous quantification of tissue and blood flow velocities within a single low-VENC acquisition, and may provide for the evaluation of diastolic dysfunction and left atrial pressures from a single acquisition.

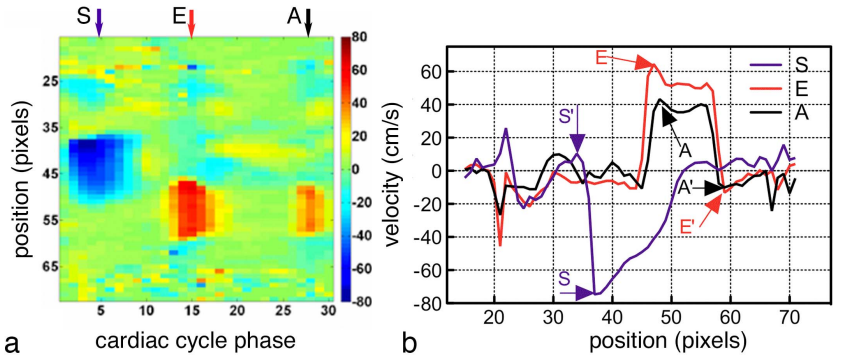

Figure 2. (a) Phase-contrast M-mode image for a line across the mitral valve (shown in Fig 1b). (b); Velocity profiles at selected cardiac cycle phases as shown by the arrows in (a): the systolic (S), early filling (E) and atrial systole (A) phases are shown.

References: [1] Galiuto et al., AJC, 81:609-614, 1998. [2] Paelinck et al., JACC, 45: 1109-1016, 2005. [3] Drexl et al., ISMRM19, p1184, 2011; [4] Buchenberg et al., ISMRM 19, p 3303, 2011. [5] Wigstrom et al., Clinical Physiology, 15: 397-407, 1995.