Nontriggered Cartesian steady-state free precession phase-contrast MR

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Introduction: Nontriggered phase-contrast (PC)-MR has been proposed for measurement of time-averaged velocity [1]. However, gradient-echo PC-MR is biased by in-flow enhancement when typical flip angles and slice widths are used, leading to velocity overestimation [2]. We hypothesize that nontriggered PC- steady state free precession (SSFP), which exhibits less signal variation over the cardiac cycle [3], will provide a more accurate mean-velocity measurement than conventional nontriggered PC-MR. This will be important for applications lacking a cardiac gating signal, such as fetal-flow measurement.

Methods: Nontriggered PC was studied in vitro with scans performed on a 1.5 T MR system (Signa Excite, GE Healthcare) using an 8-channel phased-array cardiac coil. Pulsatile flow was produced using a computer-controlled servomotor and gear pump connected to 10 mm inner diameter tubing looped through the scanner. The phantom fluid was doped (water with 0.13 mmol/L gadopentetate dimeglumine) to produce a relaxation time comparable to blood (T1 = 1200 ms).

Cine PC-SSFP data were acquired with TR/TE 3.9/1.7 ms, 1 average, flip 50°, FOV 28×28 cm, slice thickness 5 mm, matrix 256×256, 14 views-per-segment, 132 cm/s through-plane encoding velocity, prospective gating, 29 cardiac frames, and sequential phase-encode order. Nontriggered PC-SSFP data was then synthesized by re-sampling the cine data to mimic a sequential k-space acquisition. Averaging of multiple consecutive acquisitions of the nontriggered k-space was simulated, corresponding to a 10 s maternal breath hold for fetal-flow studies. For comparison, cine PC-MR data was acquired with identical scan parameters except for TR/TE 4.8/2.6 ms, flip 20°, 6 views-per-segment, 125 cm/s encoding velocity, and 27 cardiac frames. Nontriggered PC-MR was synthesized similar to PC-SSFP. Mean velocities were measured from both cine and nontriggered data using a common ROI, after background phase correction.

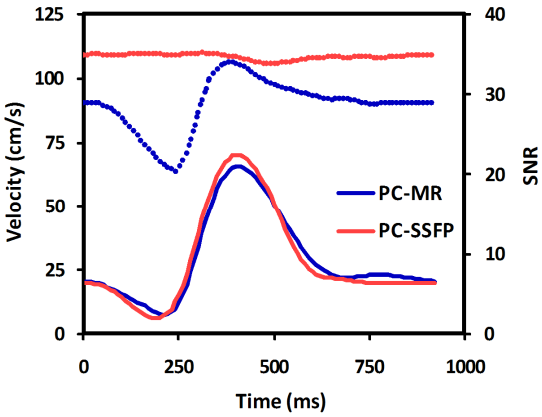

Fig. 1 Velocity (solid lines) and SNR (dotted lines) measured with cine PC-MR (dark blue) and PC-SSFP (light red).

Results and Discussion: Fig. 1 shows velocity and SNR measured from cine PC-MR and PC-SSFP. PC-MR SNR was noticeably affected by in-flow bias while PC-SSFP SNR was relatively homogenous. This in-flow effect leads to overestimation of velocity for the nontriggered PC-MR results in Fig. 2, while nontriggered PC-SSFP yielded an accurate mean velocity. Error bars show the distribution of measured mean velocity synthesized for all possible acquisition starting times in the cardiac cycle which is primarily a result of the relationship between the sequential k-space filling pattern and the fixed period of the flow pattern used to synthesize the nontriggered data. Alternative k-space sampling patterns (i.e., non-sequential Cartesian) are expected to reduce this second error.

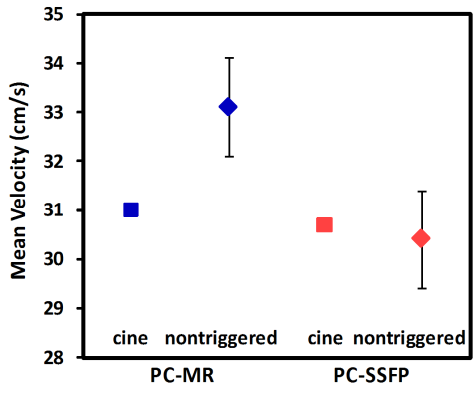

Fig. 2 Mean velocity and standard deviation measured from cine (squares) and nontriggered (diamonds) PC-MR (dark blue) and PC-SSFP (light red).

In this feasibility study, only sequential Cartesian k-space trajectories were studied. Trajectories that symmetrically oversample the origin of k-space (e.g., spiral) may record mean velocities more accurately [4]. However, imaging parameters must be chosen to reduce in-flow effects, at the expense of SNR. A radial PC-SSFP acquisition may confer the benefits of both central k-space oversampling and the insensitivity of SSFP to in-flow bias. This will be investigated in the next stage of the project, together with non-sequential Cartesian sampling. In conclusion, nontriggered PC SSFP shows promise for applications where a cardiac trigger cannot be obtained, such as fetal flow measurement.

References: [1] Hofman MRM 29(5):648 (1993) [2] Bakker MRI 13(7):959 (1995) [3] Markl MRM 49(5):945 (2003) [4] Park MRM 49(2):322 (2003)