

Flow-Encode Only Phase Contrast Magnetic Resonance Imaging

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INTRODUCTION: Evaluation of arterial hemodynamics by time-resolved phase contrast (PC) MRI is often helpful for determining the appropriate course of therapy for peripheral artery disease (PAD) (1,2). PC MRI is created by the subtraction of interleaved data sets acquired by the pair-wise application of two different gradient moments. Unfortunately, gradient-induced eddy current and concomitant field effects generate spatially varying phase errors that do not cancel with the subtraction of non-identical gradient waveforms. Phase correction algorithms are required to minimize such errors (3), but the correction is imperfect. Flow-encode only (FEO) is a novel PC method that quantifies blood-flow velocity by performing only flow-encoded acquisitions. Eliminating the paired gradient scheme (Fig. 1) improves temporal resolution by a factor of two and avoids the need for background phase correction. Blood-flow measurements by FEO PC and traditional 2D PC MRI (2DPC) were compared in healthy subjects and patients with PAD.

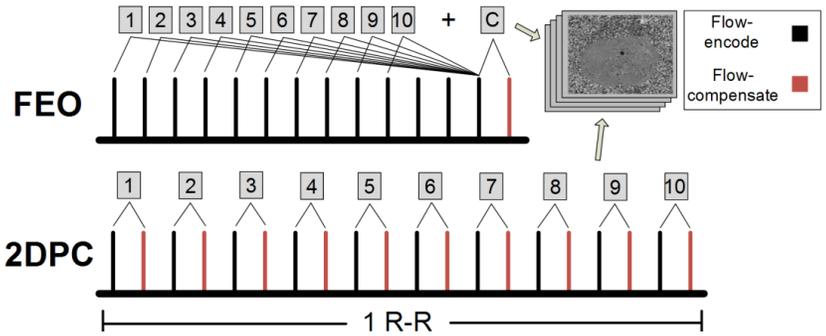


Figure 1. Flow-encode only (FEO) and traditional 2D phase contrast (2DPC) sequence diagrams. Each numbered box represents a cine frame derived from the phase difference between two readouts. "C" represents the correction frame that is added to each earlier frame of the FEO cine.

METHODS: FEO PC MRI acquires a series of flow-encoded readouts followed by a single flow-compensated readout at the end of the cardiac cycle. Each flow-encoded readout is phase subtracted from the final flow-encoded readout in the acquisition window, producing a series of PC images which are scaled to velocity. A correction image is calculated by phase subtracting the final flow-encoded readout from the flow-compensated readout. It is subsequently added to every frame in the FEO cine. The correction image is used to correct for quantification errors when there is non-zero flow during the final flow-encoded readout. 2DPC and FEO were acquired axially at 1.5T (MAGNETOM Avanto, Siemens Healthcare) in ten healthy subjects and two PAD patients at the left/right SFA and infrarenal aorta. Methods were compared with flow profiles, Bland-Altman plots and linear correlation analysis. Measurements of peak systolic flow velocity, peak reverse flow velocity, average flow velocity over the cardiac cycle, and net flow over the cardiac cycle were also compared. Statistical significance was determined with paired t-tests ($p < 0.05$). Imaging parameters for 2DPC and FEO: 240 x 320mm FOV, 240 x 320 matrix, 5mm slice thickness, bandwidth 625 Hz/pixel, 2.29ms TE. Repetition times were 20ms and 10ms respectively. The velocity encoding parameter for both methods was set at a value of 20 cm/s greater than the peak flow velocity.

RESULTS: The methods showed a strong linear correlation ($r = 0.997$, $p < 0.01$). Excellent correspondence of flow profiles between the two methods was observed (Fig. 2). Net flow, average flow velocity, peak systolic flow velocity, and peak reverse flow velocity measurements at the three examined vessels showed no statistically significant difference between the methods. Bland-Altman analysis showed a small mean difference in flow velocity (-0.87 - 0.38 cm/s) at all measurement locations in healthy subjects and patients.

DISCUSSION: Results indicate that blood-flow velocity measurements are similar between methods. FEO benefits from a doubled temporal resolution, which may help detect shorter time-to-peak delays (2) and resolve complex or highly variable flow (4). The correction image is calculated by the phase subtraction of non-identical gradient waveforms; therefore background phase errors do not cancel. Adding the correction image to the FEO cine may introduce these phase errors. Also, due to the collection of only one flow-encoded reference readout in the cardiac cycle, FEO is sensitive to motion artifact. Breath-holding may be helpful for evaluation of the abdominal aorta.

REFERENCES: 1. Moran PR. MRI 1982. 2. Mohajer K, et al. JMRI 2006. 3. Bernstein MA, et al. MRM 1998. 4. Papaharilaou Y, et al. JMRI 2001.

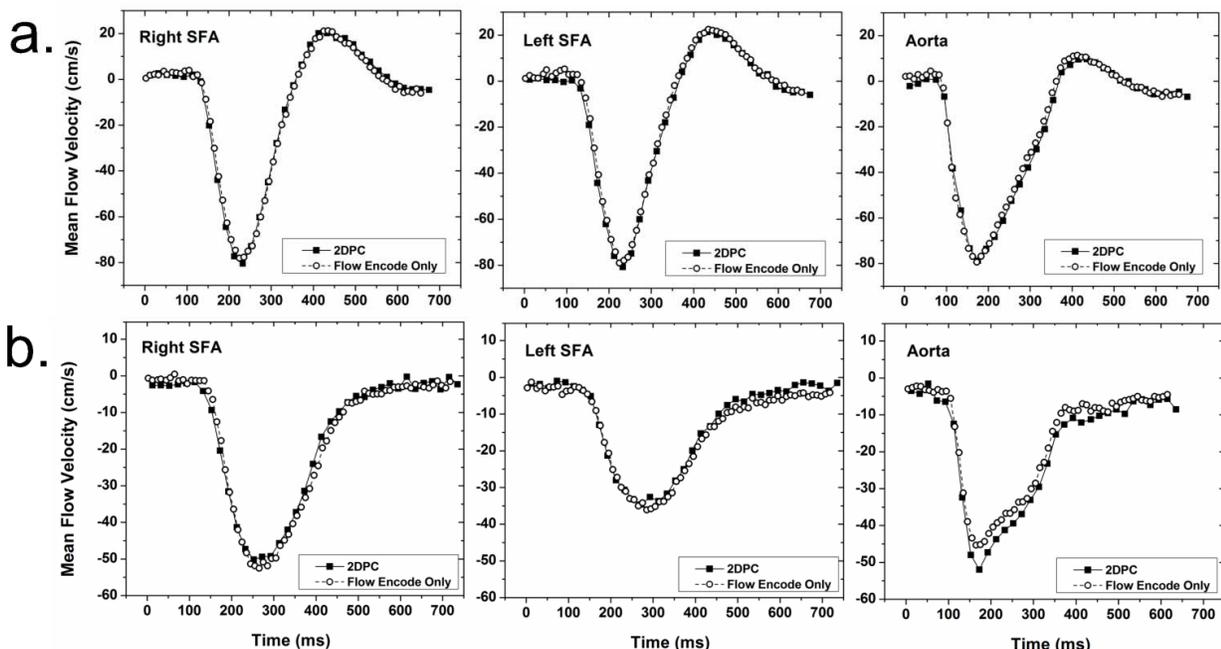


Figure 2. Flow profiles of FEO and 2DPC in **a)** healthy subject and **b)** patient with PAD. Flow velocity values at each time point were calculated as the mean of the velocities within a circular region encompassing the vessel lumen.