High temporal resolution phase contrast MRI using SSFP

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Introduction: Phase contrast MRI (PCMRI) provides flow information similar to 2D echocardiography without the restrictions of acoustic windows. However, conventional PCMRI is limited in the temporal resolution that can be achieved due to the need to implement bipolar gradients, while minimizing eddy current effects. PC-SSFP, phase contrast using SSFP, has been recently developed [1] to acquire PC data at higher rates without sacrificing contrast-to-noise ratio (CNR). Recently, a novel multiecho SSFP sequence called phase train imaging (PTI) has been proposed (Figure 1) [2] which permits acquisition of very high temporal resolutions in a single breathhold. In this approach, the same phase encoding value is used for each echo in the multi-echo readout and assigned to a different cardiac phase; when combined with parallel imaging approaches, this permits high temporal resolution acquisition in a breath-hold. In the current abstract, a 2-echo PCPTI is developed to encode through-plane and in-plane motion. In this approach (Figure 2), a fly-back gradient is employed between the two readout echoes, and a bipolar flow encoding gradient is played out in either the slice-select or the phase-encoding direction during the duration of the flyback. Thus, the first echo provides the reference data, and the second echo provides the flow-encoded data. The PCPTI sequence is implemented in conjunction with TSENSE; and the coil sensitivity maps were derived from the non-flow-encoded echo (echo 1), and used for both echoes (non flow-encoded and flow-encoded). In the PCPTI approach, each echotrain (i.e. train of echoes between RF pulses) provides one data point for the phase difference map; thus the temporal resolution for the phase contrast MRI was equal to the TR of the sequence (6 ms)

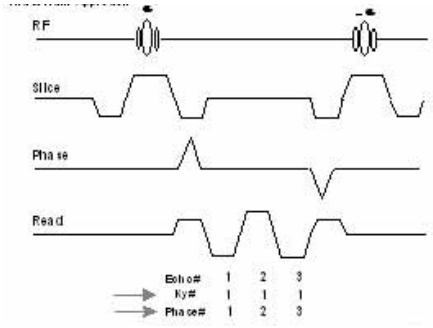

Figure 1. Phase Train Imaging

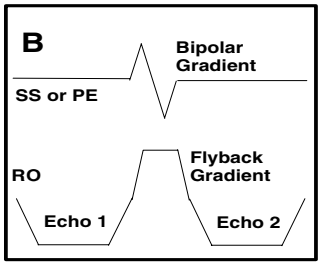

Figure2. Dual-echo phase contrast approach

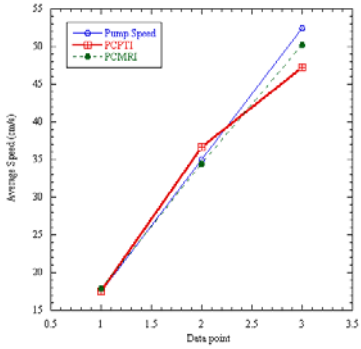

Figure3. Flow Phantom studies

Methods: The phase contrast PTI (PCPTI) sequence was implemented on 1.5T and 3.0 T TIM scanners (Siemens Medical Solutions, Malvern, PA) and tested on a flow phantom and humans . The flow phantom consisted of a blood-mimicking fluid flowing in a straight section of acrylic tubing connected to a MR-compatible pump (CardioFlow1000 MR, Shelley Medical Imaging Technologies, Toronto, Canada). For comparison, a conventional manufacturer supplied PC-FLASH cine sequence was also used to acquire flow data. Sequence parameters were: **PCPTI:** Echotrain: 2, TR/TE: 6 ms / 1.8 ms (to the first echo), flip angle: 20^0, field-of-view: 370 x 277.5 mm^2, Resolution: 256 x 48 pixels, SENSE rate: 2, breathhold duration: 24 heartbeats, total phases acquired: 150, acquisition window/heartbeat: 900 ms. **PCFLASH:** TR/TE: 52 / 2.9 ms, flip angle: 30^0, field-of-view: 320 x 240 mm^2, Resolution: 256 x 126 pixels, Segments: 7, breathhold duration: 20 heartbeats, retrogated phases: 16, Venc: 150 mm/s. For PCPTI, phase difference (PD) data was calculated as $PD = \theta_2 - \theta_1$ where $\theta = \tan^{-1}(S_i/S_r)$, 1 and 2 refer to the first and second echoes in the echotrain, and i and r represent the imaginary and real parts of the complex signal S. In the PCPTI approach, each echotrain (i.e. train of echoes between RF pulses) provides one data point for the phase difference map; thus the temporal resolution for the PD study is equal to the TR of the sequence.

Results: Figures 3 shows the flow phantom results for flow speeds between 15 and 55 cm/s, while Figures 4 and 5 show the results for through-plane flow encoding in human imaging, respectively. Figure 4 shows the through-plane velocity in the descending aorta (in the vicinity of the inferior mesenteric) of a normal volunteer (at 1.5T) , while the through-plane velocity in the ascending aorta for a Dor-procedure patient, post-surgery, is shown in Figure 5.

Discussion: The PCPTI approach correlates very well with the conventional PCFLASH sequence in tracking the velocity component in the through-plane direction. The PCPTI sequence provides the highest temporal resolution to-date for looking at through-plane flow patterns, with each dataset being acquired in a single breathhold. Flow phantom studies show good correlation between the two measurement techniques. The high temporal resolution data clearly illustrates the underestimation of peak velocity (figure 4, 80 cm/s vs 95 cm/s), as well as the timing of peak velocity (210 ms versus 240 ms), by conventional PCMRI techniques.

References: 1. Markl M, et al. MRM 2003 May; 49(5):945-52. 2. Pai VM, Proc SCMR 2005.

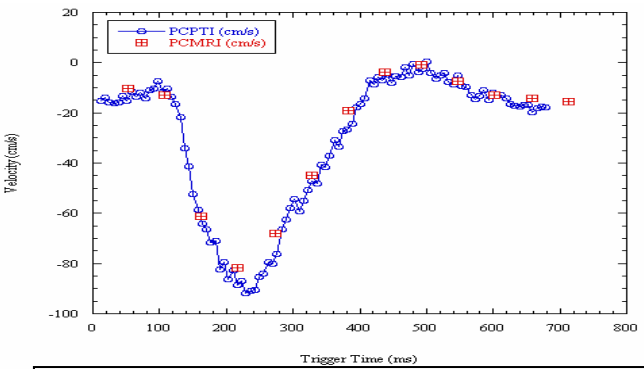

Figure 4. Through-plane velocity in the descending aorta near the inferior mesenteric artery for a normal volunteer (@ 3T)

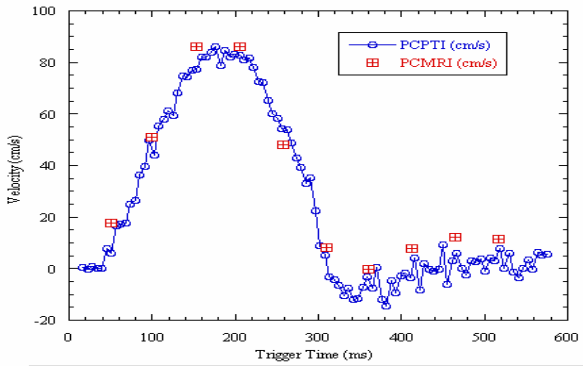

Figure 5. Through-plane velocity in the ascending aorta for a Dor procedure patient (@1.5T).