Phase contrast ultra short TE; a more reliable technique for measurement of high velocity turbulent stenotic jets

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Introduction: The measurement of peak velocities, velocity time integrals and flow is vital for accurate classification of aortic stenosis (AS). Phase contrast (PC) magnetic resonance (MR) is a potential alternative to the current clinical standard, Doppler ultrasound, but its accuracy and reliability in the moderate-severe AS patients with very high velocity turbulent stenotic jets has been questioned. Accurate PC velocity measurements rely on all the spins in a voxel to be moving with the same velocity. When the voxel's velocity range becomes too large, signal loss is seen in the magnitude image and the mean velocity estimate becomes unreliable. Many flow mechanisms inherent in a high velocity stenotic jet (e.g. accelerations, turbulence, shear) act to worsen this intravoxel dephasing. We have previously shown that these effects can be reduced by shortening the echo time (TE) [1]; however, the extent that the TE can be shortened is limited; therefore we aimed to develop and evaluate a PC implementation of an ultra short TE (PC-UTE) sequence that: a) minimises TE; b) measures velocity over the shortest possible time window; and c) reduces intravoxel dephasing and other errors associated with velocity measurement.

Methods: A conventional PC sequence consists of selective slice excitation, velocity encoding/compensation, Cartesian readout, and spoiling along the slice select axis (figure 1a). The proposed PC-UTE sequence utilises the inherent velocity sensitivity of the slice select gradient [2] to achieve the desired velocity encoding (Venc) and centric-radial readouts to minimise TE (figure 1b). A second image is acquired by inverting the velocity dependent slice select gradient.

Three sequences were investigated in a high velocity stenotic phantom (i) a TE 2.85ms retrospectively gated 15 heart beat breath-hold conventional PC sequence with flow compensation on the read and slice directions (standard clinical sequence, figure 1a), (ii) a TE 2.05ms highly tuned version (not standard product) with shortened RF pulse (500µs) and larger gradients; and (iii) a prospectively gated 15 heart beat breath hold implementation of the proposed PC-UTE sequence. The flow rate was varied from 100-700mL/s (average plug flow velocity at constriction 89-626cm/s) and in the case of the PC-UTE was extended to the maximum possible (1080mL/s and 965cm/s). To demonstrate the feasibility of using the PC-UTE sequence *in-vivo*, an aortic stenosis patient was imaged with the standard clinical conventional PC sequence and the PC-UTE sequence at the aortic root, the sino-tubular junction and in the ascending aorta.

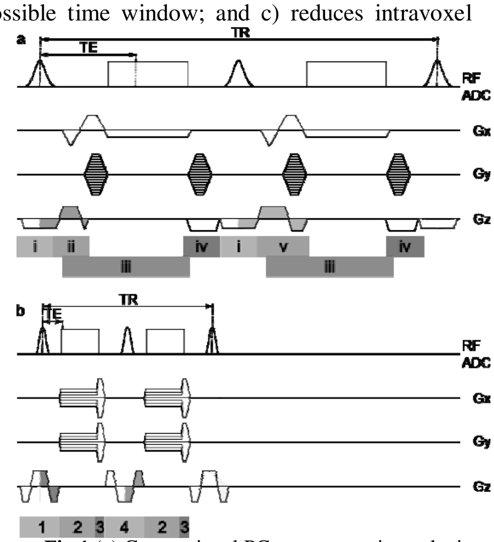

Fig 1 (a) Conventional PC sequence using velocity encoded and velocity compensated acquisitions, (b) the proposed PC-UTE sequence utilises gradient inversion velocity dependent selective slice excitation

Results: The conventional PC sequence and the optimised variant underestimate the phantom's flowmeter measurement as the flow rate is increased beyond 400mL/s and 550-650mL/s respectively, figure 2. In contrast the PC-UTE sequence exhibits good linearity with the flowmeter even at high flow rates. *In-vivo* the conventional PC sequence, (figure 3) shows signal loss surrounding the enhanced signal of the jet at the aortic valve; signal loss corresponding to the jet region at the sino-tubular junction and at the ascending aorta signal loss occurs in the centre of the vessel. In comparison the PC-UTE exhibited a more even signal to noise ratio across the whole vessel at each of the three levels.

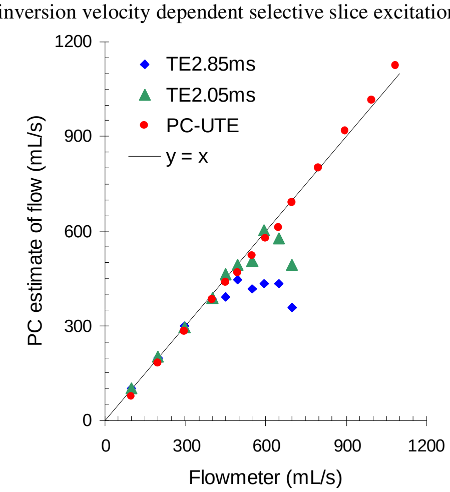

Fig 2 Comparison of the PC estimate of flow with a flowmeter in a high velocity stenotic phantom

Discussion: The PC-UTE can reduce TE from 2.85 to 0.65ms at a Venc of 500cm/s. The use of the velocity dependent selective slice excitation means that the minimum slice thickness is now dependent on the desired Venc. At a Venc of 500cm/s, most commonly used in AS examinations, the minimum slice thickness that can be achieved is 8.75mm. In our implementation the RF pulse is played out during the gradient plateau. Given this design restriction we believe that the approach that we have used yields the shortest TE; has less inherent higher order motion encoding; and measures velocity over the shortest possible time window, which leads to reduced intravoxel dephasing. As can be seen in figure 2, this allows us to significantly extend the range of velocities we can measure in the stenotic phantom. Centric radial sampling decouples TE from the resolution, and hence higher spatial resolutions are possible with high precision.

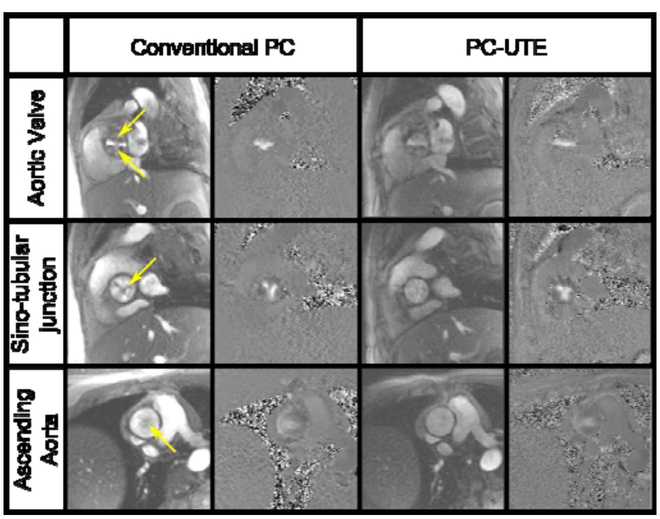

Fig 3 Conventional PC magnitude images exhibit signal loss at each level. The PC-UTE sequence has good signal across the whole vessel.

Conclusions: PC-UTE sequences or their variants provide PC images that are more robust to intravoxel dephasing present in high velocity turbulent jets. A clinical study is now required to validate this method.

References: [1] O'Brien et al. Phase Contrast Errors in Stenotic Jets JMRI2008;28:210
[2] Markl et al.. Balanced Phase-Contrast SSFP MRM 2003:49:945