5-point, ultra-short TE, 3D Radial Phase Contrast: Improved characterization of complex and turbulent flow

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Introduction: With recent improvements in acquisition schemes and speed, 3D, CINE, Phase Contrast (PC) MR is increasingly being utilized. However, it is well understood that the accuracy of PC MR is deteriorated by flow features common to pathology such as acceleration, unstable flow, and turbulence. Recently, ultra short TE 2D radial sequences have been shown to provide more reliable through plane flow measurements than standard PC [1]. Meanwhile, investigators have utilized conventional 3D PC sequences for the measurement of turbulence kinetic energy using signal losses in magnitude images with different flow encodings [2]. In this work, we investigate a synergistic combination of ultra-short TE 3D radial trajectories and a 5-point velocity encoding scheme for improvements in both the velocity measurement accuracy and estimation of intra-voxel standard deviations utilized for turbulence mapping.

Methods: Minimizing spatial and flow encoding times in turn minimizes the artifacts associated with displacement and intra-voxel dephasing. In 3D PC, substantial time is spent for phase encoding and flow compensation along the readout gradient. As shown in Figure 1, we utilize a center out, true 3D radial trajectory to eliminate the time for flow compensation and phase encoding. This in combination with a high performance gradient system allows the acquisition of sub-millisecond TE's compared to 3-4ms TE's for standard sequences. To compensate for SNR losses from the 3D radial trajectory and allow for optimal determination of intra-voxel standard deviations, a SNR efficient 5-point encoding strategy consisting of a standard Hadamard encoding scheme with the additional acquisition of a flow compensated reference is utilized [3]. With standard velocity processing, this improves the velocity to noise ratio (VNR) by 60%. Additionally, the isotropic distribution of the 4 flow encoded points with respect to the flow compensated point makes this encoding scheme ideal for intra-voxel standard deviation estimates calculated using the difference in magnitude images. Standard Cartesian 3D PC and 5-point UTE 3D PC scans were acquired on a 3T system (MR750; GE Healthcare, Waukesha, WI). Phantoms with stensoses of 0, 25, 50, and 75% were imaged with flow rates of 3, 6, 9, 12ml/s. Sequences shared common protocol parameters: resolution=0.5x0.5x0.5mm^3, FOV =14x14x14cm^3 and V_{enc}=180cm/s. The UTE 3D PC scan achieved a TE/TR of 0.96/4.1ms, compared to the standard PC TE/TR of 3.1/6.2. To compensate for increased flow saturation, the UTE PC sequence utilized a flip angle of 6° vs. 10° for the standard PC sequence.

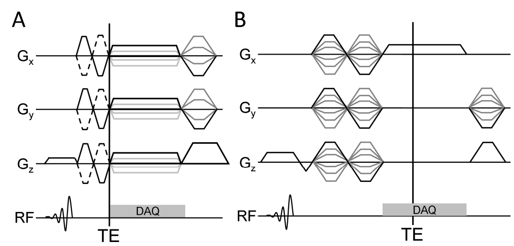

Figure 1. Pulse sequence for UTE 3D PC (A) which provides sub-millisecond TE's by starting at the center of k-space, compared to a standard 3D PC sequence with TE's on the order of 3-4ms.

Results: Figure 2 shows representative velocity and magnitude images acquired at 3ml/s and 9ml/s. At low flow rates, standard PC accurately represents the flow velocities and maintains uniform signal intensity across the stenosis. However, once physiological flow rates are approached, artifacts appear in standard velocity images. Within the stenosis, significant acceleration artifacts cause a distortion of the measured velocity. Flow measurements at maximal narrowing (white arrow Figure 2) were 5.64 ml/s vs. 9.02ml/s measured proximal to the stenosis. Additionally, significant signal loss is seen distal to the stenosis especially near a connecting tube. Substantially better vessel uniformity is achieved with the 3D UTE PC sequence. Flow measurements made proximal and at maximal narrowing were 8.99 and 8.77 ml/s respectively. In UTE PC images, signal is substantially more uniform which improves the dynamic range utilized for IVSD measures as shown in Figure 3. At high flow, significant signal loss and artifacts in source images lead to a substantially different IVSD for UTE and Standard PC sequences. Standard PC estimates high IVSD in the center of the stenosis where flow is expected to be more laminar and lower IVSD distal to stenosis, where turbulent, vertical flow is expected.

Conclusion: We have presented a technique that significantly improves the reliability and accuracy, and provides an internal quality measure of 3D phase contrast scans. Particularly in cases of complex pathology, ultra-short TE 3D radial trajectories have the potential to improve velocity measurements in stenotic jets, aneurysms, and at the vessel wall.

Acknowledgements: We gratefully acknowledge GE Healthcare and NIH Grant #2R01HL072260-05A1 for their assistance and support.

References: [1] O'Brien *et al.* MRM 62(3):626 [2] Dyverfeldt *et al.* MRI 27(7):913 [3] Johnson *et al.* ISMRM 09 # 3799

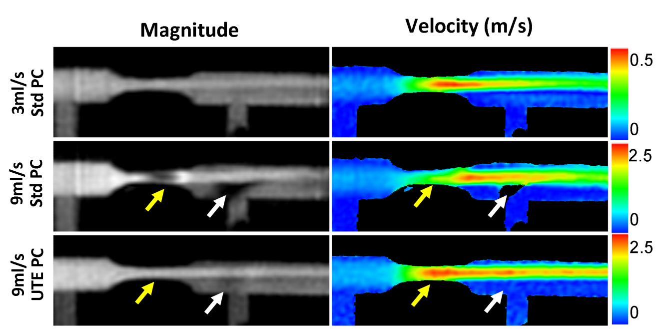

Figure 2. Velocity images of 50% stenosis phantom for two representative flow rates. Standard PC shows acceleration induced errors (yellow arrows) and signal loss from turbulent or unstable flow (white arrows) which are not present on the 3D UTE PC sequence. Colormap chosen to highlight contour changes.

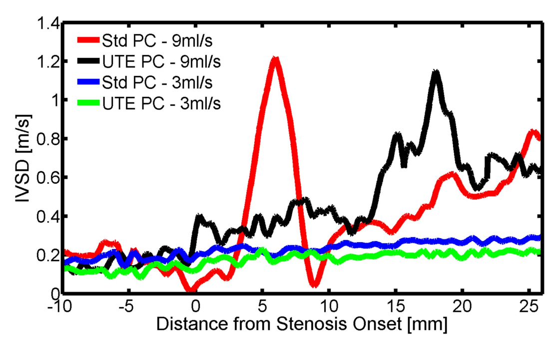

Figure 3. Intravoxel standard deviation as a function of position along the vessel. Strong agreement between UTE and Standard PC is maintained at low flow but not at high flow.