4D UTE Flow: A Novel 4D Ultra-Short TE Phase-Contrast MRI Technique for Assessment of Flow and Hemodynamics

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Introduction

Phase-contrast (PC) MRI is a reliable non-invasive technique for characterization and quantification of blood flow and flow abnormalities. 4-D flow MRI has been recently investigated in several studies for quantitative flow assessment and visualization of complex flow patterns [1-2]. This technique results in more anatomical information and comprehensive assessment of blood flow as well as shorter total scan time compared to 3-D flow imaging which requires separate 3-D scans for each flow direction. However, conventional 4-D PC MRI is challenged in the presence of atherosclerotic disease and vascular stenosis due to intravoxel dephasing secondary to disturbed blood flow, and turbulence distal to narrowings, resulting in flow-related artifacts. Previous studies have shown that shortening the echo time (TE) reduces flow-related artifacts and improves velocity and flow estimation. Ultra-short TE (UTE) PC MRI revealed a shorter TE and improvement in flow quantification in disturbed and turbulent blood flow in the through-plane direction [3]. To take advantage of 4-D flow MRI as well as short TE, in this abstract, we studied the UTE technique with 4-D flow imaging and investigated the resulting 4-D UTE PC MRI technique for flow assessment and flow visualization.

Methods

3-D UTE PC MRI was previously presented for flow assessment in one direction based on center-out radial readout gradient [3]. This sequence results in the TE shorter than 1 msec, leading to reduced intravoxel dephasing and signal loss in presence of disturbed and turbulent flows [4]. By applying the flow encoding gradients in all three directions in an interleaved fashion in this technique, flow assessment in all three directions using a single scan is feasible. Figure 1 demonstrates the 4-D UTE PC MRI sequence in which for each time frame, three separate flow encoded scans (each of which with flow encoding only in one of x, y, and z direction) and one flow compensated is acquired. The flow volumes were acquired by subtracting each flow encoded volume from the flow compensated volume. Imaging was performed on a Philips Achieva 1.5T scanner using a combined 16-element SENSE Neurovascular coil. Five normal volunteers were studied using the conventional 4-D PC MRI with Cartesian read-out as well as the proposed 4-D UTE PC MRI sequence which has center-out radial read-out trajectory which combines the refocusing lobe of the slice select gradient with the bipolar flow encoding gradient resulting in significantly reduced TE. The scan parameters for two sequences were TE/TR = 4.4/7.7 ms (for Cartesian trajectory), TE/TR = 1.6/6.7 ms (for UTE trajectory), FOV= 160*160*50 mm, sampling density of 50% for UTE trajectory, Venc= 150 in all three flow directions, flip angle= 10, spatial resolution= 1.5*1.5 mm, 12 cine frames in each cardiac cycle, and total scan time of 6:16 min for Cartesian and 6:19 for UTE trajectory. Flow assessment was performed in carotid artery in an axial 3-D volume with 10 slices and a slice thickness of 5 mm. The volume was located 15 mm (including 3 slices) proximal to and 35 cm (including 7 slices) distal to the carotid bifurcation. Center-out k-space lines are sensitive to phase error due to gradient delays, eddy currents, and B_0 field inhomogeneity. This phase error was corrected using a phase correction technique based on auto-correlation technique by scanning a static phantom prior to main scan with identical parameters to in-vivo scan [3].

Results

Flow assessment and analysis were performed in right CCA and ICA using conventional 4-D PC MRI and the proposed 4-D UTE PC MRI. Figure 2 demonstrates the Bland-Altman analysis representing mean flow difference between the two techniques in right CCA and ICA for all cardiac phases in five volunteers. The Bland-Altman plot in the right ICA show more error compared to conventional technique due to higher phase error in these slices which are located off-center of volume and suffer from more system imperfection related error. Figure 3 illustrates the flow pathlines acquired using GTFlow software (Gyrotools, Zurich, Switzerland) in both conventional 4-D Cartesian and 4-D UTE PC MRI. Flow pathlines reveal a reasonable correspondence between two techniques but 4-D UTE PC MRI flow visualization has a slight error due to UTE-related phase errors. We note that the strength of the 4-D UTE method is expected to be in the setting of atherosclerotic disease, valvular heart disease, or coarctation of the aorta where the conventional method has been reported to have significant flow-related artifacts.

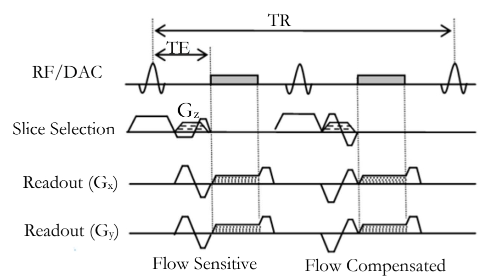


Figure 1. The proposed 4-D UTE-PC MRI sequence. The flow sensitive and compensated scans are acquired through applying three bipolar gradients in three directions. Note that each of the bipolar gradients are applied in separate TRs and for simplicity they are all shown in one TR.

Conclusion

A novel 4-D UTE PC MRI technique was presented which benefits from significantly shorter TE when compared to conventional 4-D PC MRI with Cartesian read-out. The proposed technique revealed feasibility of accurate flow visualization and quantification in healthy carotid arteries compared to conventional 4-D PC MRI technique. The shortened TE has the potential for more accurate flow assessment in case of stenosis in carotid bifurcation and ICA, suffering from intravoxel dephasing and signal loss and resulting phase error. In future studies, further phase error correction in off-center slices in 3-D volume need to be assessed in addition to flow assessment in the case of disturbed and turbulent flow.

References

[1] Harloff A, et. al., Magn Reson Med, vol. 61, pp. 65-74(2009). [2] Markl M, et. al., J Magn Reson Imaging, vol. 25, pp. 824-31(2007). [3] Kadbi M, et. al., 34th Annual Int. Conf. IEEE EMBS, 372-376(2012). [4] Kadbi M, et. al., 34th Annual Int. Conf. IEEE EMBS, 77-81(2012).

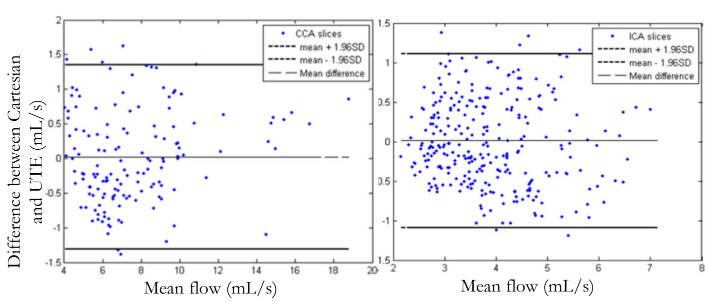
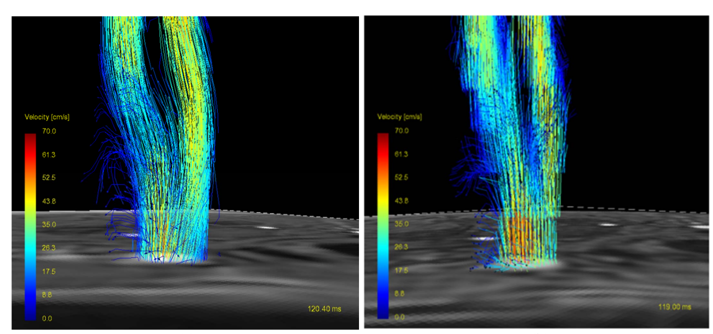


Figure 2. Bland-Altman plot demonstrating the mean flow difference between conventional 4-D flow and 4-D UTE PC MRI for all cardiac phases in five normal volunteers in (a) RCCA (mean difference=0.02 mL/s, confidence range = [-1.31,1.34]) and (b) RICA (mean difference=0.01, confidence range = [-1.09,1.11])



(a) (b)

Figure 3. Flow pathlines in carotid artery during peak systolic phase of cardiac cycle using conventional technique (a) and 4-D UTE PC MRI.