3D Isotropic High Resolution T1 Insensitive Flow Suppression using Time Efficient Phase Sensitive Double Inversion Recovery

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Introduction: Contrast-enhanced black-blood vessel wall imaging is a promising technique aimed primarily at detection of components, neovasculature and inflammation in atherosclerotic plaque. Currently, Quadruple Inversion Recovery (QIR) prepared TSE is a common black blood technique to image the pre- and post-contrast enhanced vessel wall since it has the advantage of highly insensitive to T_1 variations in a wide range with sufficiently effective blood suppression impact[1]. This QIR prepared TSE sequence, however, is limited in the acquisition efficiency due to the rather long preparation process and relatively short TSE echo trains. Also, this technique suffers from the partial volume effect caused by the large slice thickness. Recently, a multislice/2D Phase Sensitive Double Inversion Recovery (PSDIR) method was proposed to suppress blood signal in coronary artery as an inversion time (TI) independent approach [2, 3]. In this study, a time efficient 3D isotropic high resolution PSDIR with T_1 insensitive flow suppression vessel wall imaging sequence was investigated to replace the conventional QIR sequence and assessed in volunteers.

Methods: The sequence diagram of QIR prepared TSE and PSDIR based TFE is illustrated respectively in Fig. 1. Gradient echo based sequence was selected to improve time efficiency for high resolution acquisition and to fully exploit the differences in phase between the inflow and static magnetization. A secondary acquisition, which was exactly the same as primary acquisition except no DIR preparation, was performed after primary acquisition to correct phase errors caused by B_0 inhomogeneity afterwards. ***Simulation:*** The normalized M_z of blood (M_z^b) in the steady state of QIR and DIR preparation was simulated with a broad range of T_1 value. The optimal values of TI_1 and TI_2 for QIR, given TR = 800ms, were calculated by minimizing the integral of absolute M_z^b over T_1 values from 200/100ms to 1800ms [1]. This simulation result shown in Fig. 2 basically reveals that DIR prepared magnetization has the capability to significantly improve the image contrast after introducing the phase message and this improvement can be maintained in a highly T_1 insensitive pattern if the TI is sufficiently short. Here we assigned TI = 200ms to balance the outcome of flow suppression and the local restrictions, such as blood-flow velocity and the slab selective inversion thickness. This TI is obviously shorter than any pair of optimal TI_1/TI_2 for QIR that means more acquisition time per IRTR is left. ***MR imaging:*** 3 healthy volunteers (2 males, mean age 23) undertook this comparative experiment using a Philips Achieva 3.0T scanner with dedicated 8-channel phased array carotid coil. PSDIR based TFE sequence was performed with the following parameters: FOV 160x160x10mm^3, isotropic resolution 0.7x0.7x0.7mm^3, flip angle/phase sensitive flip angle = 20°/7°, TE = 2.3ms in order to avoid the water fat separation by locking them in-phase, IRTR = 1600ms and total scan time = 2:11 minutes while the parameters for QIR prepared TSE were almost identical except that the resolution was adjusted to 0.6x0.6x2mm^3 and TE/TR = 10/800ms with the echo train length of 10. The optimal QIR parameters TI_1/TI_2 = 376/130ms for T_1 ranging from 200ms to 1800ms was used. The MR imaging was centered in carotid bifurcation. ***Data analysis:*** Both datasets were reconstructed and analyzed at the Philips MR work station.

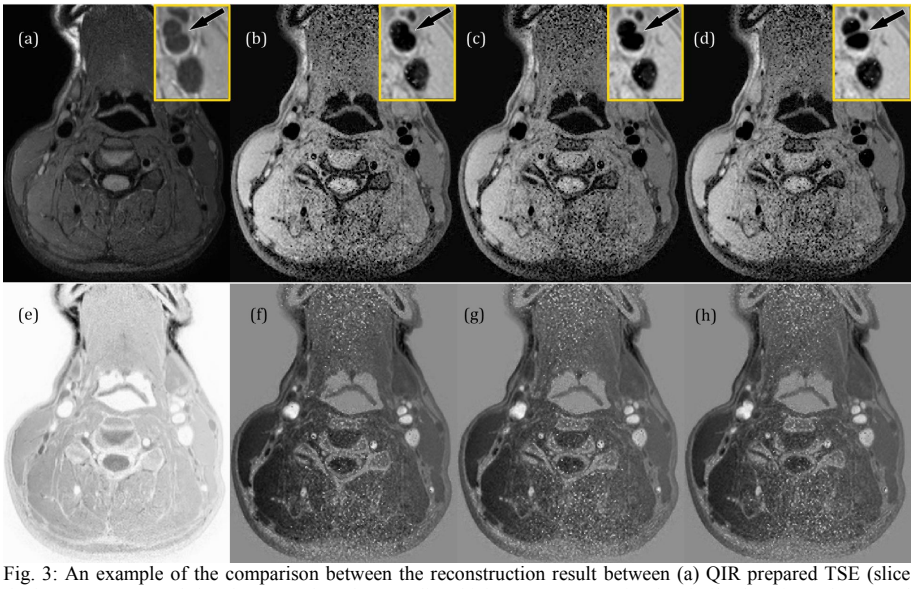

Fig. 3: An example of the comparison between the reconstruction result between (a) QIR prepared TSE (slice thickness = 2mm) and (b,c,d) PSDIR based TFE (slice thickness = 0.7mm) for the similar location. The second row is the negative value of the first row.

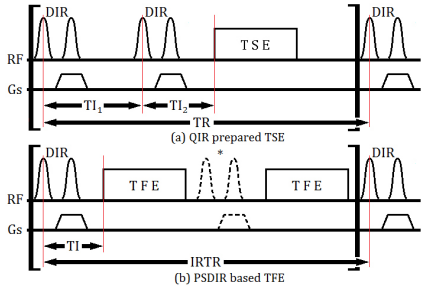

Fig. 1: Schematic comparison between (a) QIR prepared TSE sequence and (b) PSDIR based TFE sequence. *: no DIR module.

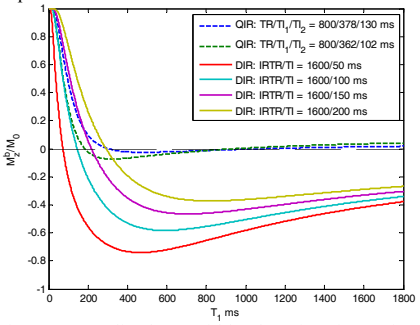

Fig. 2: Normalized M_z of blood as functions of T_1 for QIR (dash line) and DIR (solid line) preparations is simulated respectively.

Results: Fig. 3 displays an example of typical comparison between these two sequences at a similar location. We can find that 3D isotropic high resolution PSDIR based TFE generally generates adequate "nulling" of the blood signal even if deliberately narrowing the image window. We can also invert the polarity of data to obtain an additional TOF image after some post-processing since the blood signal is not truly zero as QIR. Besides, the CNR between lumen and vessel wall has been improved from 117.73+/-14.07 in QIR sequence to 565.06+/-50.13 in PSDIR sequence while the acquisition efficiency of PSDIR based TFE is nearly 3 times beyond the QIR prepared TSE.

Discussion and Conclusion: This study explained the TI independent CNR enhancement and T_1 insensitive properties of PSDIR in principle and investigated a time efficient 3D isotropic high resolution PSDIR based TFE imaging sequence in practice. This proposed sequence provided better flow suppression and reduced the preparation duration and SAR value in QIR prepared TSE sequence dramatically. The results of this study also suggested that the proposed technique with a better T_1 insensitive flow suppression might be a useful tool for dynamic contrast enhanced black and white blood vessel wall imaging.

References: [1] Yarnykh VL, et al. Magn Reson Med. 2002 Nov;48(5):899-905. [2] Abd-Elmoniem KZ, et al. Magn Reson Med. 2010 Apr;63(4):1021-30. [3] J. Xie, et al. ISMRM 2011, Montreal, 1265.pdf.