Partial Fourier acquisition with centric circular reference lines in 3D MRI

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Introduction: Partial Fourier acquisition, which makes use of the conjugate symmetry of k-space for data recovery, has been combined with various k-space undersampling techniques, i.e. parallel imaging[1], compressed sensing[2] etc., to reduce the MR scanning time. Extra reference lines are acquired in k-space center because of several reasons: i) phase correction before exploiting the k-space symmetry; ii) coil sensitivity estimation in parallel imaging; iii) improving convergence speed of iterative algorithm. These reference lines are often acquired in a 'rectangular' pattern in 3D Cartesian k-space (Fig1.a). However, the 'rectangular' pattern is suboptimal in case of restricted number of reference lines. In this work, the defects of partial Fourier acquisition with 'rectangular' reference lines are discussed, and the advantages of an alternative 'centric circular' pattern (Fig1.b) are investigated with in vivo experiments.

Theory: In 'rectangular' pattern, the estimated phase information in the partial Fourier direction has much lower frequency than that in its perpendicular direction, so phase errors are strongly concentrated in a single direction, which leads to more visible artifacts in the reconstructed image. In 'centric circular' pattern, phase errors are uniformly distributed in all directions, so the maximum intensity of artifacts is reduced to lower level than that in 'rectangular' pattern. Moreover, partial Fourier acquisition is employed in TSE sequence to achieve the contrast of intermediate TE, and alleviate blurring due to T2 decay in long echo train acquisition. Fig2 shows the combination of partial Fourier acquisition with the shifted radial flexible reordering in SPACE sequence [3]. Because the number of views acquired at the left side of the k-space is strictly determined by the position of effective TE in the echo train, the total number of reference lines should be the same in both 'rectangular' pattern and 'centric circular' pattern if using identical parameters. Despite the strongly asymmetric distribution of the phase errors in two phase encoding directions, one more defect of the 'rectangular' pattern (Fig2. a) is that more echoes close to the effective TE are encoded to the outer part of k-space, and fewer concentrated in the k-space center than those in the 'centric circular' pattern (Fig2.b), which leads to poorer contrast purity in 'rectangular' pattern.

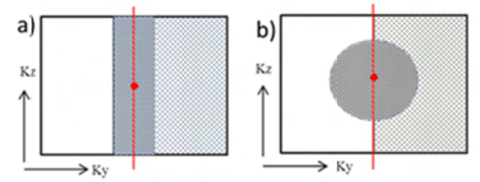

Fig1. Shaded regions denote the partial k-space acquisition in 3D imaging; heavily shaded regions denote the acquired reference lines with 'rectangular' pattern (a), and with 'centric circular' pattern (b).

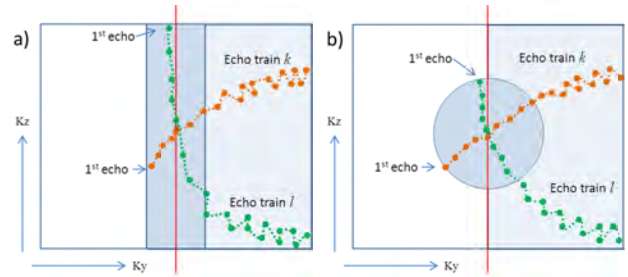

Fig2. The combination of partial Fourier acquisition and the shifted radial reordering in SPACE sequence; a) with 'rectangular' reference lines; b) with 'centric circular' reference lines. Both partial Fourier acquisition patterns have the identical number of reference lines. Comparing their train trajectories, the first echo of train *l* in a) has been encoded to outer k-space region, but all the echoes for reference lines in b) are efficiently concentrated around k-space center, which alleviate the T2-decay caused signal intensity variation in k-space, and provides higher contrast purity.

Method: The partial Fourier acquisition, including both 'rectangular' pattern and 'centric circular' pattern, is combined with k-space random undersampling for compressed sensing reconstruction in 3D GRE and SPACE sequences. In the experiment with 3D GRE sequence, a complete k-space was acquired on the MR scanner, but randomly undersampled with both partial Fourier acquisition patterns during offline reconstruction (Fig3. b, e). The images were reconstructed with compressed sensing algorithm in Matlab [4]. In the experiment with SPACE sequence, similar sampling patterns were applied already during the data acquisition.

Results: In Fig3., in the experiment of 3D GRE, the reconstructed image using partial Fourier acquistion with 'centric circular' pattern (Fig3.f,g) shows reduced recontruction errors compared to that using the 'rectangular' pattern (Fig3.c,d). In the experiment of SPACE, partial Fourier acquistion with 'centric circular' pattern provides better delineation of knee cartilage, and fewer alising artifacts due to k-space undersampling (red arrows in Fig3 h, i).

References: [1] Griswold MA et al, MRM 2002, 1202-1210; [2] Doneva M et al, ISMRM 2010:485; [3] Li G et al, ISMRM 2009: 2623; [4] Lustig M et al, MRM 2007, 1182-1195;

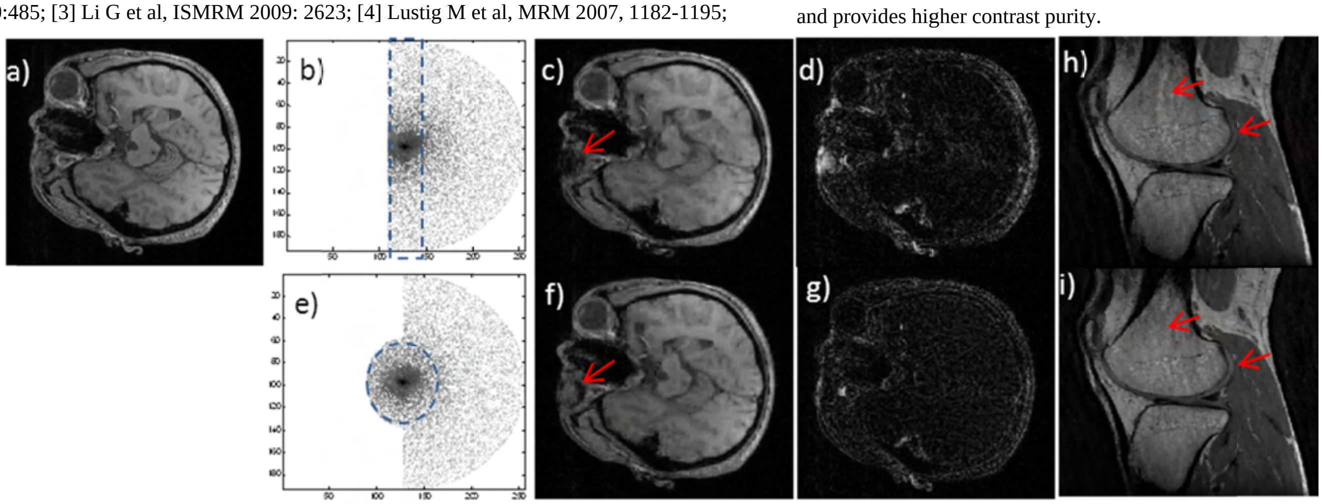

Fig3. a) standard image reconstructed from the fully sampled k-space by 3D GRE; b) k-space random sampling with 'rectangular' reference lines (dashed box); c) reconstructed image from b); d) reconstruction error in c); e) k-space random sampling with 'centric circular' reference lines (dashed circle); f) reconstructed image from e); g) reconstruction error in f); h) reconstructed image from k-space acquired by SPACE sequence, with the similar acquisition pattern in b); i) reconstructed SPACE image with the similar acquisition pattern in e);