

The shifted radial reordering for intermediate TE imaging in 3D long echo train acquisition

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Introduction Use of nonselective pulses and modulated flip angles (aka SPACE, [2, 3, 4]) in refocusing pulses improves the sampling efficiency in 3D turbo spin echo imaging. Two flexible reordering schemes, the linear mode and the radial mode, have been proposed [1] to circumvent some intrinsic limitations of the rectangular k-space sampling grid (e.g., allowing for flexible k-space coverage) in segmented 3D imaging. The proposed radial reordering is good for ultra-short or ultra-long TE imaging, where the data from the first echo or last echo are put into the k-space center. However, it does not support intermediate TE values, which are useful in some body or orthopedic imaging applications. Compared to the linear reordering (Fig.1b), the radial reordering in intermediate TE imaging is sometimes preferred since it gives well defined contrast weighting, reduces intensity fluctuation at the k-space center as well as image blurring during Partial Fourier (PF) imaging. We propose here a method to support intermediate TE imaging using radial sampling.

Methods In this abstract, the typical radial reordering is called the centric mode. The new radial reordering scheme will be called the shifted mode (see Fig. 1c, 1d). In 3D long echo train imaging, let L = the turbo factor and represents the echo train length, M = the echo number at the k-space center and $M < L/2$. In the shifted radial reordering, each echo train represents one view going through the center region of the radial k-space. When the M^{th} echo in the echo train is defined as the k-space center, there are $L/2$ echoes on one side of the view, and M echoes along the other side. The actual echo train length in one view is shortened from L to $L/2+M$. $L/2-M$ echoes will be missing in each view. When the azimuth angle goes from 0 to π during sampling, the missing echoes may be reconstructed using PF reconstruction. The effective PF factor is given by $f_{PF} = (L/2 + M)/L$.

The mentioned flexible reordering schemes were incorporated into SPACE, implemented on a 3T clinical scanner (MAGNETOM Verio, Siemens, Erlangen). It was first tested on a phantom. Comparison was made between the linear reordering and shifted radial reordering in intermediate TE imaging. Parameters for the phantom experiment were: RO x PE x SL = 320x270x167, turbo factor $L=70$, $M=9$, Partial Fourier factor=0.63, TE/TR=44ms/1000ms, refocusing flip angle = 150 degree. The technique was then tested on two healthy volunteers, one for knee imaging and another for abdominal examination. Imaging parameters for the knee were identical to phantom experiment except that the refocusing pulses were variable, and optimized for T1/proton density weighted imaging [4]. For abdominal examination, the imaging parameters were: RO x PE x SL= 384 x 262 x 26, turbo factor $L=120$, $M=59$, Partial Fourier factor=0.92, TE/TR= 253ms/ 2500 ms, and the variable flip angle refocusing pulses optimized for T2 weighted imaging was used [2, 3].

Results Fig2 shows the images obtained using the linear reordering (Fig. 2a) and shifted radial reordering (Fig. 2b) scheme. The ghosting in the phase encoding direction is much reduced using the shifted radial reordering scheme. The k-space filling pattern from the shifted radial reordering scheme creates smoother modulation of the data at the k-space center, which may benefit the Partial Fourier reconstruction, especially the case with small PF factor. Fig 2c-Fig 2f show the knee images obtained using between linear reordering (Fig 2c) and shifted radial sampling (Fig. 2d). The images from the shifted radial reordering present less blurring and better delineation of the subtle structures (Fig. 2f) than those from the linear reordering (Fig. 2e). As shown in Fig3, the obvious ringing artifacts of the bladder in the image obtained by the linear reordering (Fig. 3a) disappeared in that acquired by the shifted radial reordering scheme (Fig 3b).

Discussion Results showed that the shifted radial reordering can replace the linear reordering for the intermediate TE imaging in 3D long echo train acquisition, and provides better image quality. Compared to the linear reordering, the echo train trajectories always pass through the k-space center region with different directions, the shifted radial reordering may be insensitive to some slow motion artifacts (like the respiratory motion shown in Fig3). In the shifted radial reordering, the transfer modulation may produce discontinuity in the k-space along the reference axis (where the azimuth angle=0), which introduces ringing artifacts in the image domain. Applying the reference axis along the direction with fewer encoding steps can reduce this discontinuity (Fig.1d). When the k-space acquisition matrix in the K_z - K_y plane varies from square to rectangle (Fig. 1c, 1d), the shifted radial reordering becomes similar to the linear reordering.

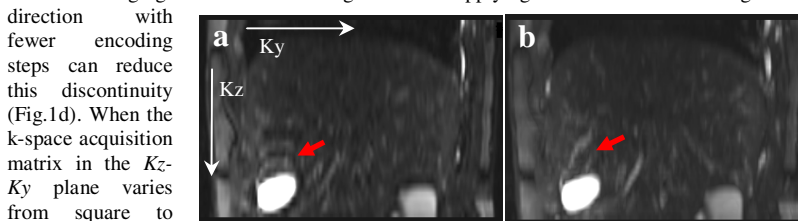


Fig3. The MPR images in the K_z - K_y plane from the abdomen examination using clinical parameters, obtained a) by the linear reordering, b) by the shifted radial reordering.

References

- [1] Busse. ISMRM 2008, p837; [2] Mugler, MRM, 1990;
- [3] Mugler, ISMRM 2006, p2429; [4] Jaeseok Park, MRM, 2007, p982.

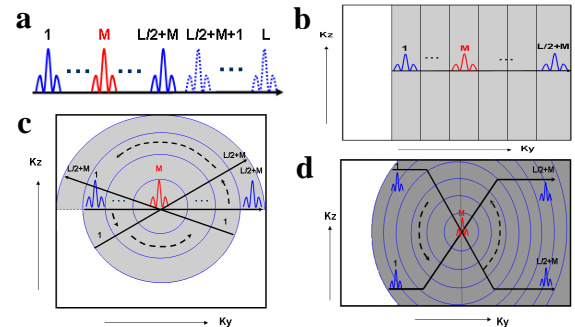


Fig1. a) The echo M denotes the desired TE value, L = the turbo factor, the acquired echoes are shown from 1 to $L/2+M$, Partial Fourier reconstruction is applied; b) shows the general echo train trajectories in the linear reordering; c) and d) show the trajectories in the shifted radial reordering; In c), the number of the K_z steps is close to that of the K_y steps; In d) is the case that the number of the K_z steps is much smaller than that of the K_y steps.

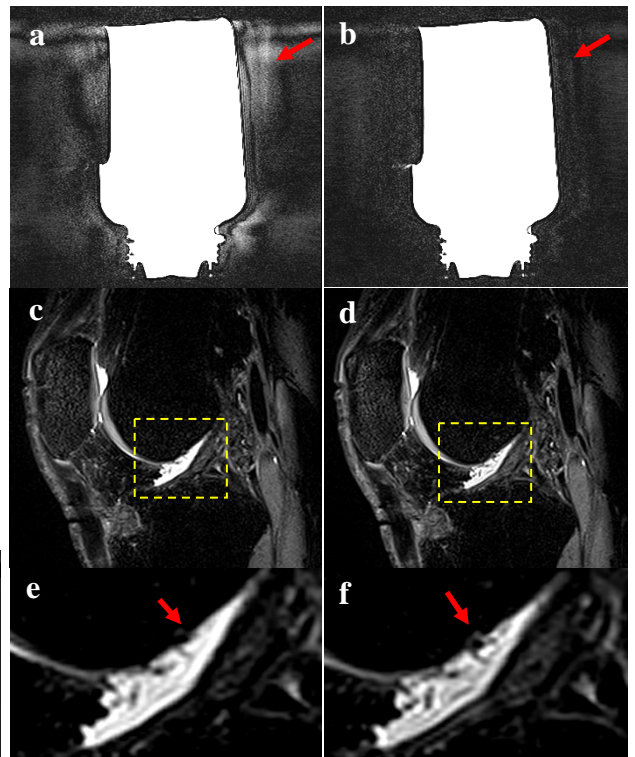


Fig2. a) phantom image obtained by the linear reordering; b) phantom image by the shifted radial reordering using the same parameters as in a); c) knee image obtained by the linear reordering; d) knee image by the shifted radial reordering using the same parameters as in c); e) magnification of the rectangular region in c); f) magnification of the rectangular region in d)