SNR Improvement and Reduction of geometric distortion in 3D SingleShot Diffusion-Weighted STimulated-EPI (3D ss-DWSTEPI)

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INTRODUCTION 3D singleshot DW STimulated-EPI (3D ss-DWSTEPI) [1] was developed for high-resolution DTI. The sequence acquires the entire 3D k-space data from a localized volume after a single diffusion-weighting preparation. 3D ss-DWSTEPI suffers from a low SNR because it uses only half the diffusion-weighted magnetization stored into the longitudinal plane by a 90° RF and spoils the other half. This reduces the image SNR by 2. The degree of susceptibility-induced distortion in EPI-type acquisitions is inversely proportional to the speed of the k-space traveling in the phase-encoding direction, which is proportional to the phase FOV. To improve the SNR and reduce susceptibility-induced distortion, 3D ss-DWSTEPI in-plane readout is shortened by reducing the FOV in the phase-encoding direction. The new reduced FOV (rFOV) approach is used to image a small FOV in the phase direction without aliasing artifacts from the signal outside the imaging FOV. In this report, a parallel imaging technique has been implemented in 3D ss-DWSTEPI to further reduce the geometric distortion and a method has been developed to improve the SNR by utilizing the whole diffusion-weighted magnetization.

METHODS Parallel imaging was implemented only in the phase-encoding direction, because the number of slice-encodings in 3D ss-DWSTEPI is small (8 ~ 24). The original 3D-ss-DWSTEPI was modified to acquire reference data (ET_{PI}) for parallel imaging as shown in Fig.1. The ET_{PI} dataset was only acquired once for multiple repetitions. In order to compensate for the T_1decay of diffusion-weighted magnetization, a variable flip angle scheme ($\alpha_1 \ldots \alpha_n$) was implemented. In the original 3D-ss-DWSTEPI, the diffusion weighted magnetization that had been left in the transverse plane after the tip-up 90° RF pulse was spoiled. In the new 3D-ss-DWSTEPI, this magnetization is sampled by the echotrain ET_0 (Fig. 1). The k_z=0 plane of 3D k-space is sampled twice by ET_0 and ET_1 readouts. To improve image SNR, these readouts are combined as follows. The ratio between the peak magnitude S_{ET0} of the echotrain ET_0 and S_{ET1} of ET_1 was calculated as SF = max(S_{ET1})/ max(S_{ET0}) and used to scale the ET_o readout down to the same magnitude as that of the corresponding image ET_1 readout. Two echotrains ET_0 and ET_1 were then combined to construct new k-space data (ET_{new}) for k_z=0 using the expression: $S_{new} = (S_{ET1} + SF \cdot S_{ET0})/2$.

Acceleration factor (R) was set to 2 for ET_0-ET_n readouts. Each readout covers the complete k_x-k_y plane for 3D k-space. To reconstruct missing k_y views in the readouts, multi-dimensional realization [2, 3] of the GRAPPA algorithm [4] was implemented. The missing k_y lines were found according to the reconstruction coefficients computed from reference data acquired by ET_{PI} readout (Fig.1).

Imaging studies were performed on a 3 T clinical MRI system (Trio-Tim, Siemens Medical Solutions, Erlangen, Germany) with Avanto gradients (40 mT/m strength and 150 T/m/s slew rate) using a 12-channel head coil. Phantom images were acquired using 3D ss-DWSTEPI sequence with the following imaging parameters: slab thickness 20 mm, bandwidth 1.086 kHz/pixel, TR/TE 4000/61 ms for R=1 and 4000/46 ms for R=2, FOV 256x120 mm, acquisition matrix 128x60x10, and b 100 s/mm² along the slice direction .

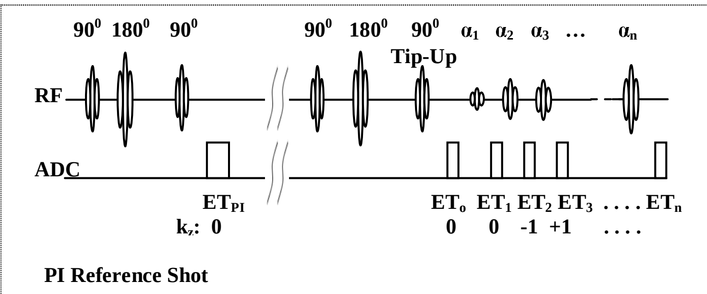

Figure 1: Schematic diagram of 3D-ss-DWSTEPI combined with Parallel Imaging (PI) data acquisition. Reference data for multi-dimensional GRAPPA reconstruction is acquired by ET_{PI} readout. 90° RF Tip-Up pulse transfers half diffusion-weighted magnetization to the longitudinal plane. This magnetization is sampled by ET_1, ET_2, … ET_n readouts. Each readout covers the complete k_x-k_y plane for different k_z views. Flip angles ($\alpha_1, \alpha_2, \ldots \alpha_n$) for the readouts are adjusted according to a variable flip angle scheme [1]. Another half of the magnetization is sampled by ET_0 readout immediately after the 90° RF Tip-Up pulse. Both ET_0 and ET_1 readouts acquire k_z=0 plane of 3D k-space.

RESULTS AND DISCUSSIONS The images shown in Fig.2 demonstrate the improvements in 3D ss-DWSTEPI image quality: (a) → (b): reduction of geometric distortion using parallel imaging, (b) → (c): SNR improvement using the combined k_z=0 data, (d): difference image between (c) and (b). The SNR of the R=2 image is higher than that of the R=1 image due to a shorter TE for the R=2 image. The actual ETLs were 60 and 30, and corresponding TEs were 61 and 46 ms for R= 1 and 2, respectively. The SNR of image (c) increased about 10% compared with that of image (b). This was because the k_z=0 plane of 3D k-space dataset was sampled twice and the data were combined. This method may induce a ghosting artifact if the phase of two k_z=0 data sets, i.e., ET_0 and ET_1, are not consistent.

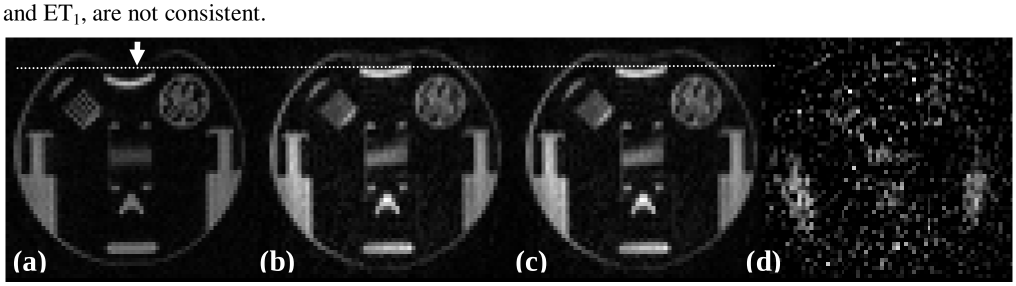

Figure 2 Phantom images (a) and (b) reconstructed from complete data (R=1) and partial data (R=2), respectively. The vertical arrow indicates a shift of the water signal due to the local field variation. The horizontal dotted line is the guideline to measure the geometric shift due to the local susceptibility field. The susceptibility artifact was halved using parallel imaging with R=2. Image (c) was reconstructed using parallel imaging and the new k_z=0 data (weighted sum of ET_o and ET_1). Image (d) is difference image between image (c) and image (b).

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