ARTIFACT FREE 3D FAST SPIN ECHO IMAGING USING A SINGLE EXCITATION

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Introduction: Fast spin echo (FSE) or RARE plays a central role in clinical imaging. High resolution 3D FSE with flip angle modulation (1) provides T2 weighted images that can be reformatted in any desirable plane. However, violation of the CPMG condition within the volume of interest results in image artifact. This artifact is very prominent at off-center locations such as shoulder and wrist. In a recent publication we presented a technique to overcome this problem using a two-excitations approach in conjunction with a low resolution phase correction (2). In this abstract we present a method to reduce scan time to a single excitation with a parallel imaging (PI) technique.

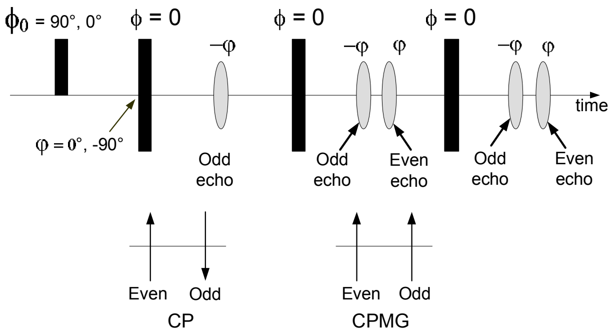

Fig. 1

Theory: Fig. 1 shows an FSE sequence. Each echo in the train can be divided into two pure echoes (3): An even echo that experience an even number of phase inversions and an odd echo with odd number of inversions. Consequently, a phase φ before the first refocusing pulse phase-shifts each even echo by φ and each odd echo by $-\varphi$. The phase of all the refocusing pulses is $\phi = 0$ and the phase of the 90° excitation pulse is ϕ_0. If ϕ_0 is 90° (CPMG excitation) then $\varphi = 0°$, both echoes are in phase. If ϕ_0 is 0 (CP excitation) and $\varphi = -90°$, the echoes are 180° out of phase from each other. This is described schematically in Fig. 1 by two arrows, where for CPMG and CP the arrows point in the same and opposite directions respectively. In order to reconstruct an artifact-free image (2), the goal is to separate the even and odd echoes.

Method: In 3D FSE we phase-encode along k_y and k_z and use ~100 echo trains to acquire the full 3D data set. Hence we control which echo train (CP or CPMG) is acquired at which point on the k_y-k_z plane (1). In the original scan (2) we acquired a full k_y-k_z 3D data set with a CP excitation and another k_y-k_z data set with CPMG excitation. After Fourier transformation (FT) each spatial point (y, z) is a linear combination of an even and an odd echo and the echoes are separated by adding/subtracting both data sets. To reduce scan time we acquire only one k_y-k_z data set, and separate the even and odd echoes at each (y, z) point with PI. Since we can acquire each k-space point with either CP or CPMG, the CP/CPMG data acquisition order is interleaved so as to minimize the g factor (4) and obtain a more accurate even/odd echo separation. The lowest g factor is reached when the even echo and odd echo images are spatially shifted so the PI inversion matrix (4) is full rank. CP/CPMG data acquisition order in k-space and the resulting even/odd echo location in the y-z plane are shown in Fig. 2. A triangle represent data from a CP echo train and a circle represent data from a CPMG echo train. In Fig. 2a CP/CPMG data is shifted from each other along k_y (y shift) and in 2b along k_y and k_z (y-z shift). The odd-echo image in Fig. 2b is shifted in both y and z, so we expect a lower g factor there.

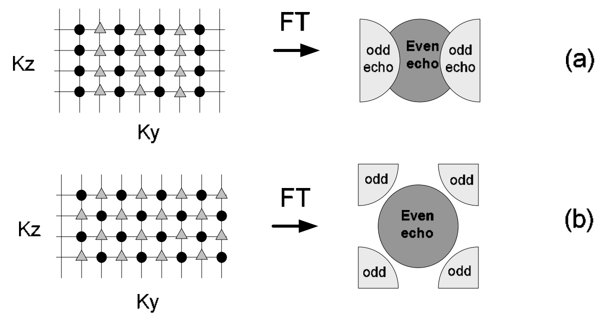

Fig. 2

Image Reconstruction: 3D PI is done using ARC (5) (method 5 in reference (6)). To find the ARC weights we acquire a low-resolution complementary k_y-k_z data with 20 x 20 lines. The image reconstruction consists of 1) Acquire a single k_y-k_z 3D data set sampled as in Fig. 2. 2) Acquire low resolution complementary k_y-k_z data and calculate the weights. 3) Calculate the full data with ARC. 4) Fourier-transform to y-z space and find even and odd echoes by adding and subtracting the two y-z data sets. 5) Phase-correct both echoes with a low resolution phase (2). 6) Add both echoes.

Results: Full CP and CPMG data sets from a phantom and volunteers images were acquired. To test the algorithm we removed half the data and arranged a single k_y-k_z data set as shown in Fig. 2a and 2b. A complementary k-space data of 20 x 20 lines was used to generate the weights. After reconstruction we compared the PI reconstruction error RRMS (6) between the fully sampled and PI reconstructed images. PI reconstruction was carried out with a) no shift (CP data set is synthesized from fully sampled CPMG), b) y shift (Fig. 2a) and c) y-z shift (Fig. 2b). Fig. 3 shows the center slice of a fully sampled 3D shoulder image and a PI reconstructed image with y-z shift. The Table below compares the RRMS of images with various anatomies using y, y-z and no shift. For a y shift, the RRMS depends on the coil geometry. For y-z shift the RRMS is always low. With no shift the RRMS is significantly higher.

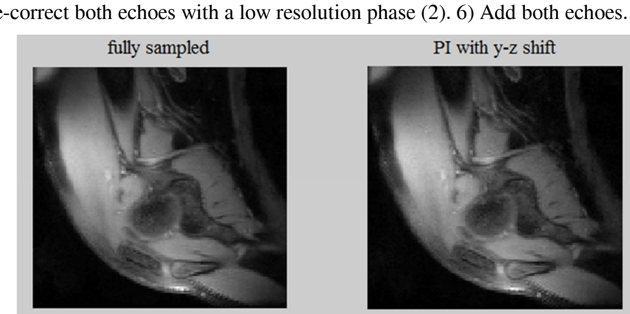

Fig. 3

Conclusion: The acquisition time of our CP-CPMG method with PI reconstruction is similar to an equivalent FSE scan. It does not depend on the CPMG condition and produces high-quality artifact-free images in any reformatted direction. However, due to the PI the signal-to-noise ratio is 30% lower compared to an equivalent FSE image.

Anatomy	RRMS no shift	RRMS y shift	RRMS y-z shift	Matrix	coils
shoulder	0.156	0.043	0.035	192x192x128	3
wrist	0.518	0.34	0.083	256x206x34	8
knee	0.111	0.042	0.044	256x256x52	8
phantom	0.199	0.040	0.045	256x256x142	8

References: (1) R. F. Busse et al. Mag. Res. Med. 2008: 60: 640-649.
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