Reducing Ghosting in EPI Using Trajectory Based Reconstruction with Dixon Method Fat Suppressed Navigator Echoes at 7T

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Introduction

7T poses fundamental challenges to performing good EPI fMRI. One of these is high SAR which can be significantly increased if fat saturation pulses are employed (1). Another is the difficulty of obtaining good B_0 and B_1 field homogeneity. As well as distortion and dropout, B_0 inhomogeneity can lead to Nyquist ghosting. Navigator echoes, acquired at short TE, before the main EPI acquisition, are commonly used to reduce Nyquist ghosts (2). Although, because of a short T2*, little fat signal remains at a TE (~25ms) suitable for BOLD imaging (1), a strong contribution can still be observed in short TE (~2.5ms) navigator echoes. At 7T, the chemical shift of fat is approximately 1 kHz and significant variation can occur in the relative fat-water phase between successive navigator echoes. This phase variation can lead directly to a systematic error in the phase correction or can cause a low navigator echo amplitude and consequent increased random error in the phase correction. In slices where fat saturation is less effective because, for example, of poor shim or locally reduced B1 field, and in those R.F. channels with a strong, localised sensitivity to subcutaneous fat signal, we show that standard navigator echo correction can be greatly impaired.

To overcome this problem we have adopted a simple, two point Dixon method (3,4) for attenuating the influence of fat in the navigator echoes. Navigator echoes, but not the main EPI acquisition, are acquired on separate repeats at two different TE's, differing by approximately half the fat chemical shift signal period. The navigator echoes acquired at the two different TE's are then summed before further processing. Whereas the water signals add coherently leading to an approximately doubled resultant the fat signal component, being significantly out of phase, is strongly suppressed. The modified navigator echoes are then applied to both EPI acquisitions from which their parent echoes were obtained.

Methods

Data were acquired from 4 volunteers on a 7T Siemens whole body system (Siemens GmbH, Erlangen, Germany) equipped with a 24 channel head array receive coil with dedicated CP coil for RF transmission (Nova Medical, Inc, Wilmington, MA, United States). The EPI sequence comprised: crusher; (optionally) frequency selective fat saturation and crusher (1); slice selective excitation; trapezoidal readout of 3 reference echoes at TE_{nav} ~ 1.5-2.5 ms; followed by EPI acquisition of 64 imaging echoes with an echo spacing of 0.5 ms and TE=25 ms. 64 slices were acquired with a slice thickness of 2 mm and inter-slice gap of 1 mm. TR=3.84 s (with fat saturation) or TR=3.2 s (without fat saturation). To test the method, the following runs, comprising 5 EPI volumes each, were acquired: Fat saturation on, TE_{nav}=2.0 ms; Fat saturation on, TE_{nav}=2.5 ms; Fat saturation off, TE_{nav}=2.0 ms; Fat saturation off, TE_{nav}=2.5 ms.

Complex time domain data were transferred from the scanner and images reconstructed offline in Matlab (The Mathworks, Inc, Natick, MA, United States). Reconstruction proceeded as follows: selection of volume 3 from each run; 1-D trajectory based reconstruction (TBR) (5) in the frequency encoded direction using k-space trajectory calibration data previously acquired from a gadolinium doped silicone oil spherical phantom; summation of navigator echoes acquired at the two different echo times, or, as a control, summation of echoes acquired at the same echo time from a separate volume (number 5); smoothing of reference echoes in the readout direction; navigator echo phase correction; 1-D Fourier transformation in the phase encoded direction; square root sum-of-squares (SoS) coil image combination (6).

The ghost level was evaluated by determining a 3-D region of interest in the background in which the Nyquist ghost varied significantly in amplitude under the different acquisition and reconstruction regimes, and then computing the mean value of signal from this region and dividing by the mean signal from the brain image, determined by amplitude thresholding.

Results

Figures 1 and 2 show slices from two representative subjects: upper row - no fat sat.; lower row-with fat sat. From left to right: no navigator phase correction; navigator correction without Dixon method; navigator correction with Dixon method. A non-linear grey scale has been used to enhance the ghost for clarity. Figure 3 shows the mean ghost : image ratio for the subject in figure 1 over the volume region of interest. The four subjects showed similar results.

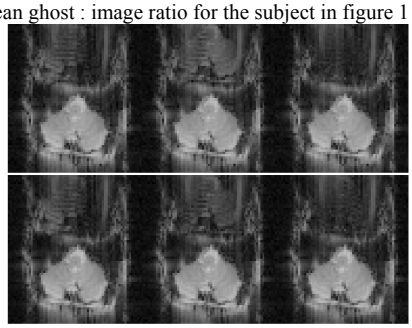

Figure 1

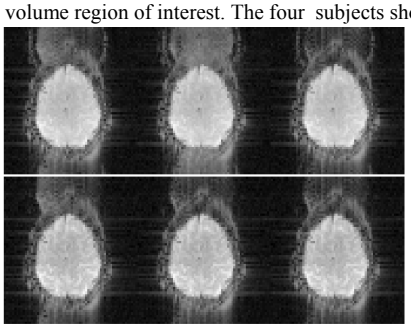

Figure 2

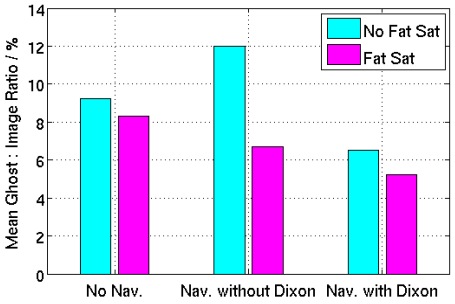

Figure 3

Discussion

The results demonstrate an improvement over standard EPI navigator methods by correcting for the confounding influence of fat signal on navigator echoes. Our experimental data suggest that the combination of TBR with Dixon Method corrected navigator echo phase correction may allow for EPI at 7T with low ghosting without using fat saturation, thereby reducing SAR and allowing for faster imaging. Our technique is independent of, and can be used in addition to, coil sensitivity based ghost reduction techniques such as PAGE (7), which might also usefully deal with residual chemically shifted fat signal as can be seen, for example, in figure 2. In the fMRI context TE_{nav} could sensibly be alternated between successive volumes. Unlike multi-shot acquisitions, no signal flicker would be expected between successive images since the image TE remains constant and the same composite navigator data are used for even and odd volumes.

References

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