Improved image reconstruction for partial Fourier gradient-echo EPI

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Introduction

The partial Fourier gradient-echo EPI technique makes it possible to acquire high-resolution fMRI data at an optimal echo time. This technique is especially important for fMRI studies at high magnetic fields, where the optimal echo time is short and may not be achieved with a full-Fourier acquisition scheme. In addition, it has been shown that partial Fourier EPI provides better anatomic resolvability than full-Fourier EPI. However, the partial Fourier gradient-echo EPI may be degraded by artifacts that are not usually seen in other types of imaging. Those unique artifacts in partial Fourier gradient-echo EPI, to our knowledge, have not yet been systematically evaluated. Here we use the *k-space energy spectrum analysis* (**KESA**) method [1] to understand and characterize two types of partial Fourier EPI artifacts. Our studies show that Type 1 artifact cannot be corrected with any pure post-processing method, and Type 2 artifact can be eliminated with an improved reconstruction method. We further propose a novel algorithm, that combines images obtained from two or more reconstruction schemes guided by KESA, to generate partial Fourier EPI with greatly reduced Type 2 artifact.

Theory and Methods

Echo-shifting effect induced Type 1 and Type 2 artifacts in partial Fourier gradient-echo EPI:

The image-domain phase accumulations due to the in-plane susceptibility field gradients cannot be refocused in gradient-echo EPI. The gradients of image domain phase values result in the shift of the k-space echo energy peaks in gradient-echo EPI. As described in a recent paper, the echo-shifting effect can be accurately quantified with KESA [1]. Here we further illustrate that the echo-shifting effect may induce two different types of artifacts that are unique in partial Fourier gradient-echo EPI, as illustrated with a simulation study (Figure 1). Figures 1a and b show the proton density map and field inhomogeneity map of our mathematical phantom, and it can be seen that there exist pronounced field gradients along the phase-encoding direction (vertical) in Region 2 and Region 3. The simulated full Fourier EPI k-space data are shown in Figure 1c. Echo energy peaks corresponding to Region 2 and Region 3 deviate from the ideal k-space center due to the local field gradients (i.e. the echo-shifting effect). The reconstructed image is shown in Figure 1d. When a partial Fourier acquisition scheme is chosen, it is very likely that echo energy corresponding to certain image domain regions will be shifted outside the sampling window. For example, if only the k-space area within the yellow box is sampled (Figure 1c), the k-space energy corresponding to Region 2 will not be acquired properly, which in turn results in signal loss in the reconstructed partial Fourier image (Figure 1e). The signal loss indicated by an yellow arrow is termed **Type 1 artifact**, which originates from the k-space energy loss and thus may not be corrected with a pure post-processing method.

In conventional partial Fourier MRI reconstruction methods, the required image background phase information can only be estimated from a central ky band (for example, the rectangular area enclosed by red line in Figure 1c). If the k-space energy peak corresponding to a certain image domain region is located outside the central ky band, then the low-resolution phase image may not provide accurate phase estimation. As a result, there may exist additional artifacts in the reconstructed image. For example, the k-space energy peak corresponding to Region 3 is located outside the ky band used for background phase estimation, and thus the reconstructed partial Fourier EPI is degraded by artifact in Region 3 (red arrow in Figure 1f). This artifact, termed **Type 2 artifact**, results solely from improper post-processing and thus may be removed with an improved post-processing method, as stated below.

Reduction of Type 2 artifact in partial Fourier gradient-echo EPI using an improved reconstruction procedure:

The improved partial Fourier EPI reconstruction algorithm, consisting of two schemes, is schematically illustrated in Figure 2. (a) In partial Fourier EPI, portions of the k-space data, i.e. in the positive ky domain (area 2) and the central ky band (area 1), are acquired. (b) The KESA is applied to identify pixels with k-space energy peaks located in k-space areas 1 and 2 (shown in a), respectively. (c) Partial Fourier reconstruction scheme 1 (i.e. the conventional partial Fourier reconstruction) is designed for pixels whose k-space energy peaks are located in k-space area 1. Data in un-acquired area 3 are calculated from data in area 2, with low-resolution background phase information estimated from data in area 1. (d) Partial Fourier reconstruction scheme 2 is designed for pixels whose k-space energy peaks are located in k-space area 2. Data in area 4 are calculated from data in area 1, with low-resolution background phase information estimated from data in area 2. (e) Mask 1 is generated to identify pixels whose k-space energy peaks are located in k-space area 1. (f) Mask 2 is generated to identify pixels whose k-space energy peaks are located in k-space area 2. (g) The output of the reconstruction algorithm is the combination of images obtained from two reconstruction algorithms, filtered with different masks.

Experiments and Results

Full Fourier gradient-echo EPI data were acquired from healthy subjects with a 1.5 Tesla system. Scan parameters included: matrix size 64 x 64, slice thickness 4mm, FOV 24cm x 24cm, inter-ky line echo-spacing time 0.592msec, and readout bandwidth 100kHz. Multiple partial Fourier EPI data sets, corresponding to different numbers of acquisition ky lines (34, 36, 38 …64), were generated from the acquired full Fourier EPI data through k-space truncation. Images of the same reconstruction matrix size (64 x 64) were then reconstructed from data sets corresponding to different numbers of acquisition ky lines using two approaches: (1) the conventional partial Fourier reconstruction algorithm, and (2) the improved two-scheme partial Fourier reconstruction method guided by KESA.

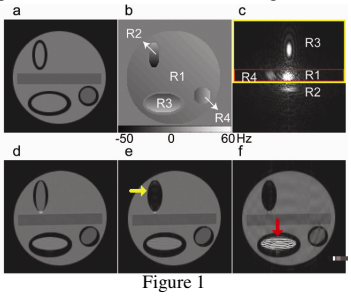

Figure 1

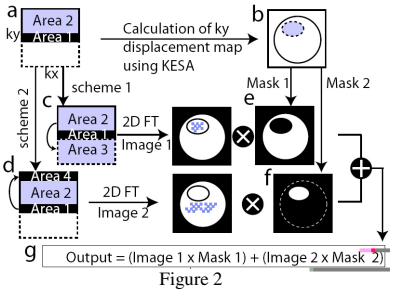

Figure 2

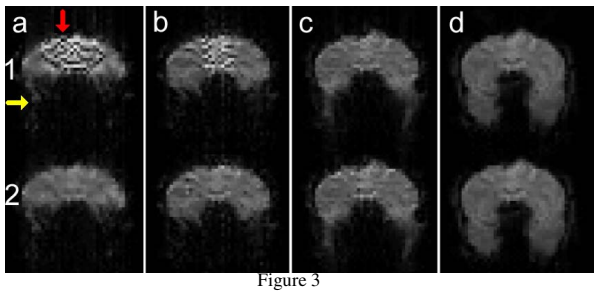

Figure 3

Images of a selected coronal-plane, corresponding to four different numbers of acquisition ky lines: 36, 40 46, and 64, are shown in Figures 3a to d, respectively. Images reconstructed using the conventional partial Fourier reconstruction algorithm, with the background phase values are estimated from the central ky band, are shown in row 1. It can be seen that both Type 1 and Type 2 artifact (indicated by yellow and red arrows respectively) decreases as the number of acquisition ky line increases.

Using the new two-scheme partial Fourier reconstruction algorithm, the reconstructed images have significantly reduced Type 2 artifact (row 2 of Figures 3a to d) in comparison to images obtained with the conventional method (row 1), particularly for data with a small number of acquisition ky lines.

In conclusion, we have used the recently developed KESA method to understand and characterize two types of artifacts that are unique in partial Fourier gradient-echo EPI. We further develop a novel algorithm, that combines images obtained from two or more reconstruction schemes guided by KESA, to generate partial Fourier EPI with greatly reduced Type 2 artifact. The developed techniques should prove useful for partial Fourier EPI based high resolution functional MRI.

Acknowledgment: NIH R21 EB005690 and NIH U41 RR019703.

References: 1. Chen N.-K. et al. Neuroimage, 2006;31:609–622.