An inverse Approach to the Recovery of Signal losses in EPI Images

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Introduction

In Echo-planar imaging (EPI), large static field inhomogeneity and the magnetic field gradients or significant changes in the susceptibility at tissue/air and tissue/bone lead to image distortions and artifacts (1). Susceptibility-related field variation along the slice-selective direction results in severe signal losses, while the in-plane inhomogeneity leads to geometric distortions (2). This paper derives and implements a method for recovering MRI signal losses caused by Susceptibility-induced magnetic field gradients (SFGs) in regions with large static field inhomogeneities in EPI. Factor to account for SFGs was added in a traditional EPI equation, which was a simple Fourier transform (FT) for expressing the actual k-space data of an EPI scan. The inverse calculation of this "distorted EPI" equation was used as a kernel to correct reduction in intensity during reconstruction. A step-by-step EPI reconstruction method is proposed to avoid complicated phase unwrapping problems.

Theory and Methods

In conventional single-shot EPI, the acquired k-space data S can be expressed in matrix form as $S=AI$. Where S is k-space, I is undistorted image, and A is the transform matrix operator, which is combined of Fourier Transform (FT) factor, SFG factor and field inhomogeneity factor. SFG factor and field inhomogeneity lead to distortion and signal losses in EPI images. Fortunately, based on previous methods (1-4), matrix A can be obtained by measuring field map (shows how much the phase of a voxel changes in different RO lines) and SFG map (shows how much the MR signal of a voxel reduces in different RO lines), then the ideal image I can be calculated from k-space based on $I=A^{-1}S$ using numerical solution methods (3), where A^{-1} is the inverse matrix of A. But direct inverse method does not provide correct result sometimes, since strong SFGs may lead to phases changing greater than 360^{o} during calculation, which bring decisive errors. Let

$$S = (A_{sfg} \Theta A_{pf})I \qquad [1]$$

where A_{sfg} is the transformation matrix operator for the SFG factor, A_{pf} is the transformation matrix operator of the FT and the field inhomogeneity factor, Θ denotes element by element matrix calculation. Now, define

$$I_0 = A_{pf}^{-1}S \qquad [2]$$

$$B = A_{pf}^{-1}(A_{sfg} \Theta A_{pf})$$

then the ideal EPI image can be shown as

$$I = \sum_{i=0}^{N} B^i I_0 + B^{N+1} I \qquad [3]$$

when N is big enough, $B^{N+1}I$ will be very small and close to 0. So, with appropriate selection of N, the ideal image without distortion and MRI signal loss can be shown as:

$$I = \sum_{i=0}^{N} B^i I_0 \qquad [4]$$

Results and Discussion

Two steps are involved to make an undistorted image: 1) take a field map scan, calculate field map and SFG map, and calculate kernels based on equations above. 2) take EPI scan(s); reconstruct image(s) using theses kernels along phase encoding (PE) direction. To calculate field map and the intra-SFG map, a voxel of the EPI should be measured in high resolution using a multi-echo gradient echo sequence. The final field map (in the same resolution of the EPI image) is produced by averaging the scanned field map and reducing the resolution into the one of EPI image. To calculate one pixel in an SFG map, all of these small voxels (one voxel in EPI) from the high resolution field map scan were resorted according to their field, and then their field gradients were calculated and averaged. The reconstruction methods described here were implemented on a 3-T siemens MR scanner system. The images were acquired using a single-shot blipped-EPI sequence. The field of view was 22x22 cm, the matrix size was 64x64, and the slice was 5-mm thick. Some experimental results of a human volunteer are shown in Fig. 1. The susceptibility difference between tissues and air cavities under this slice lead to geometric distortions and SFG-induced signal losses in EPI image shown in Fig. 1(b). Both geometric distortions and signal losses by SFGs were corrected using proposed reconstruction method shown in Fig. 1(c). Fig. 1(e) shows that if $N>5$ is used in Eq. 4, almost all of SFG-induced signal losses will be recovered in to the reconstructed EPI image I.

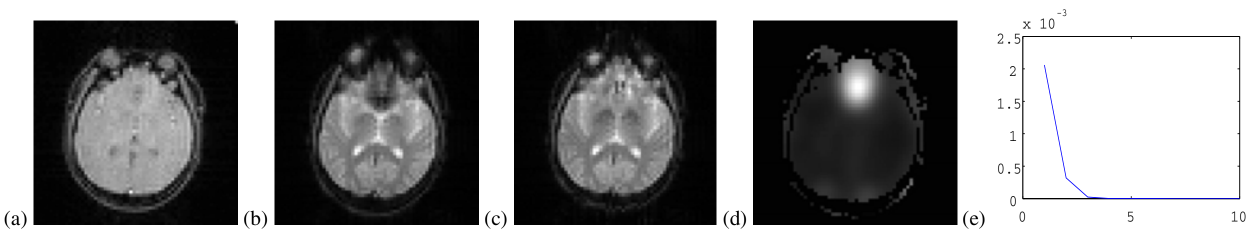

Fig.1 Gradient echo image (a), and original EPI (b), corrected EPI (c), intra-voxel SFG map (d), largest reconstructed EPI image pixel value in calculation steps (e)

References

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