Point Spread Function (PSF) Map Technique for Distortion Correction of Echo Planar Imaging (EPI) at 7T

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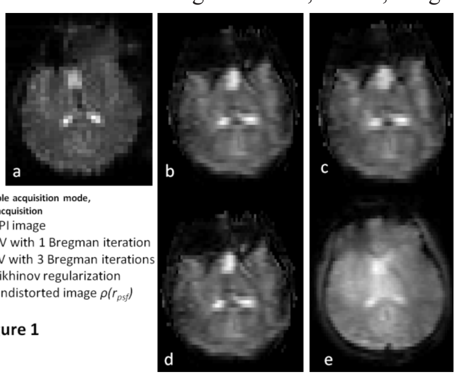
PSF mapping method[1] has been proposed to correct for the geometric distortion. We further developed the PSF mapping technique using the regularized inverse solution and dual echo acquisition strategy for EPI distortion correction at 3.0T[2], in which the first EPI readout serve the PSF mapping and the second EPI readout is the actual EPI acquisition. Its advantage is no need of the extra scan time to acquire the PSF map. With the rapidly expanding interest of fMRI study in utilizing ultra high field system, it becomes urgent to develop a robust EPI distortion correction scheme at 7.0T. We attempted to apply PSF mapping technique developed at 3.0T to test its correction efficacy at 7.0T. For functional MRI scans (fMRI) at 7.0T, the optimal TE is around 25 msec to achieve sufficient sensitivity to blood oxygenation level dependence contrast (BOLD). This makes the dual EPI echo acquisition strategy developed at 3.0T difficult to implement at 7.0T. To overcome this difficulty, the blipped phase encoding resolution was sacrificed to meet the TE requirement. We make the hypothesis that the low resolution in phase encoding direction can be partially compensated by the PSF encoding resolution in final corrected image. For comparison, we also acquired the conventional PSF acquisition for comparison without sacrificing the phase encoding resolution.

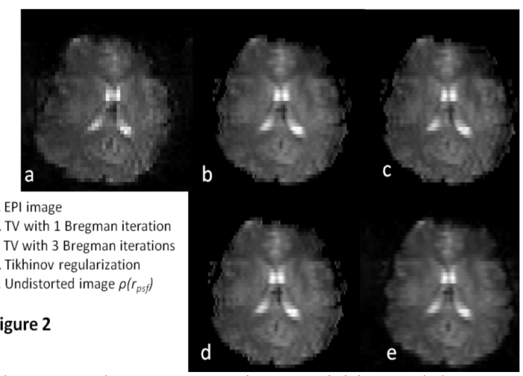
Methods: For dual EPI readout acquisition strategy, the acquisition parameters were tailored based on the 7.0T Siemens Magnetom system: The first EPI readout for PSF map encoding, matrix size 70×30, the second readout echo for EPI image, matrix size 70×48. The phase encoding resolution of the first EPI readout was 5/8 of the second EPI readout. FOV = 254mm × 254mm, TR = 4 s, slice thickness = 4.5 mm, number of slices = 15, receiver bandwidth =± 108kHz, the echo spacing was minimized to 0.41 ms after turning on the ramp sampling acquisition. PSF FOV = 254 mm, number of PSF encodings = 96. TE of PSF = 9.8ms, TE of EPI = 26.8ms. In this acquisition scheme, the EPI phase encoding resolution was reduced. For conventional PSF acquisition, FOV = 240mm × 240mm, TR = 4 s, TE = 25ms, slice thickness = 4.5 mm, number of slices = 15, receiver bandwidth =± 96kHz, the echo spacing was 0.58 ms without ramp sampling. PSF FOV = 120 mm, number of PSF encodings = 64. Whole brains were shimmed to maximize the T2* to around 16-18ms according to vendor's standard shimming procedure.

After data were processed to remove the Nyquist ghost and data regriding for ramp sampling, the PSF map H and the undistorted reference image $\rho(r_{psf})$ (Fig1e,2e) were processed as described previously[1]. Two regularized inverse algorithms, total variation (TV) regularization with Bregman iteration, were applied to the PSF map for regularized inverse solution[3]. For TV regularization with Bregman iteration, the cost function f_k, ($f_k = arg\{||g+v_{k-1}-Hf||^2+\lambda^2||f||_{TV}\}$) was minimized, such that $||f||_{TV} = \sum(\mathrm{sqrt}(f_x^2+f_y^2))$, $v_k = v_{k-1}+g-Hf_{k-1}$ for $k>0$, $v_0=0$. The first Bergman iteration is equivalent to the TV regularization, $\lambda^2 = 1$, Bregman iterations = 3; each Bregman iteration has 30 fixed-points iterations.



Double acquisition mode, 5/8 acquisition
a. EPI image
b. TV with 1 Bregman iteration
c. TV with 3 Bregman iterations
d. Tikhinov regularization
e. Undistorted image $\rho(r_{psf})$

Figure 1



a. EPI image
b. TV with 1 Bregman iteration
c. TV with 3 Bregman iterations
d. Tikhinov regularization
e. Undistorted image $\rho(r_{psf})$

Figure 2

Results: Figure 1 and Figure 2 show the results of double EPI readout PSF mapping acquisition and the conventional PSF mapping acquisition respectively. EPI images are distorted in both acquisitions. Both of them can correct the geometric distortion and restore theirs contour as shown in the Figure1 and 2. In Figure 1a, the intensity distortion is more obvious than the geometric distortion as shown in the frontal lobe area. The signals of the frontal lobe are smeared. The contrast between gray matter (GM) and white matters (WM) are not obvious either. The intensity distortion and low resolution may contribute to the low contrast. After PSF distortion correction, the intensity distortion is corrected and PSF resolution replaces the blipped phase encoding resolution. The contrast between GM and WM becomes better as shown in Figure 1 b,c,d. However, compared with Figure 2 b,c,d, the resolution improvement is limited. The images look blurred in all of the process procedures, indicating that the high frequency component is insufficient.

Conclusions: We applied the PSF mapping technique with regularized inverse solution to 7.0T. Consistent with the 3.0T data, this technique is robust at 7.0T. However, it is more difficult to implement dual EPI readout acquisition strategy due to the shorter optimal TE=25ms at 7.0T. To make it work within this time frame, we tailored the blipped phase resolution and implemented ramp sampling acquisition strategy. The PSF mapping technique is compatible with the ramp sampling. The reduced resolution can be partially compensated by the high PSF resolution in the final corrected image. However, this improvement has its limitation.

1. Zeng, H. and R.T. Constable, *Magn Reson Med*. 2002. p. 137-46.
2. Yu Cai et al, ISMRM 2313, 2011
3. Liu, B., et al, Magn Reson Med, 2009. **61**(1): p. 145-52