Self-correction of B1 inhomogeneity artifact in diffusion-weighted imaging using double-angle excitation

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INTRODUCTION: Diffusion-weighted imaging (DWI) is widely used to identify acute infarction and also to differentiate many other pathologic conditions. However, B1 inhomogeneity induced signal intensity nonuniformities may degenerate its image quality and negatively impact diagnoses, in particular at high field. A variety of amplitude-based [1, 2] or phase-based [3] RF filed mapping (B1+ mapping) methods has been developed to date. They can serve as pre-scan to calibrate the flip angles in some quantitative MRI applications such as T1-mapping, or correct the image intensity variation [4]. In the work described in this abstract, we embed the double-angle B1+ mapping mechanism in to a DW-EPI sequence via changing the flip angles of excitation pulses. With the proposed sequence and reconstruction, the B1 inhomogeneity information can be obtained from DWI images and used to reduce related artifacts in these images.

METHODS: The signal intensity of DW-EPI sequence with Stejskal-Tanner diffusion weighting scheme can be described as:

$$S = M_0 \sin\theta_1 \sin^2(\theta_2/2)\frac{(1+(\cos\theta_2-1)e^{-(TR-TE/2)/T_1}-\cos\theta_2 e^{-TR/T_1})}{1-\cos\theta_1\cos\theta_2 e^{-TR/T_1}}\times e^{-TE/T_2}\times e^{-bD}$$

where θ_1 and θ_2 are flip angles of the excitation and refocusing pulses. When $TR >> T_1$, the above equation can be simplified to:

$$S = M_0 \sin\theta_1 \sin^2(\theta_2/2)\times e^{-TE/T_2}\times e^{-bD}$$

The conventional DW-EPI Sequence uses pair of 90 (θ_1)-180º (θ_2) pulses to maximize the signal. Moreover, it often demands more than one repetition to increase signal-to-noise ratio (SNR). Herein we take the example of 2 repetitions to fulfill the requirement of double-angle B1+ mapping. We set $\theta_1 = \alpha_{\text{nominal}}$, $\theta_2 = \beta_{\text{nominal}}$ and $\theta_1 = 2\alpha_{\text{nominal}}$, $\theta_2 = \beta_{\text{nominal}}$ for each repetition and keep other scanning parameters fixed. The measured signal intensities of these two repetitions can be expressed as:

$$S_{1,\text{measured}} = M_0 \sin\alpha_{\text{actual}} \sin^2(\beta_{\text{actual}}/2)\times e^{-TE/T_2}\times e^{-bD},$$

$$S_{2,\text{measured}} = M_0 \sin 2\alpha_{\text{actual}} \sin^2(\beta_{\text{actual}}/2)\times e^{-TE/T_2}\times e^{-bD},$$

where α_{actual} and β_{actual} are the actual flip angles, which can be obtained by:

$$\alpha_{\text{actual}} = \arccos(\frac{1}{2}\frac{S_2}{S_1}), \quad \beta_{\text{actual}} = \beta_{\text{nominal}}\cdot\frac{\alpha_{\text{actual}}}{\alpha_{\text{nominal}}}.$$

Note that the calculation of β_{actual} is based on the assumption of a linear relationship between flip angle and B1+ map. For images acquired by these two repetitions, the correction factors for transmission field are consequently given by:

$$C_1^+ = \frac{\sin\alpha_{\text{nominal}}\sin^2(\beta_{\text{nominal}}/2)}{\sin\alpha_{\text{actual}}\sin^2(\beta_{\text{actual}}/2)}, \quad C_2^+ = \frac{\sin 2\alpha_{\text{nominal}}\sin^2(\beta_{\text{nominal}}/2)}{\sin 2\alpha_{\text{actual}}\sin^2(\beta_{\text{actual}}/2)}.$$

In addition, based on the principle of reciprocity, we simply take $\alpha_{\text{nominal}}/\alpha_{\text{actual}}$ as the reception correction factor C^-. Then the image intensities of these two repetitions can be corrected by:

$$S_{1,\text{corrected}} = S_{1,\text{measured}}\cdot C_1^+\cdot C^-, \quad S_{2,\text{corrected}} = S_{2,\text{measured}}\cdot C_2^+\cdot C^-$$

respectively. Theoretically, $S_{1,\text{corrected}}$ should equal $S_{2,\text{corrected}}$ when we take α_{nominal} = 60º and β_{nominal} = 180º. Thus, we take the average of $S_{1,\text{corrected}}$ and $S_{2,\text{corrected}}$ as the final output and make sure that the correction will not induce any worry of quantitative analysis.

The sequence and corresponding online reconstruction was implemented using Siemens IDEA.

EXPERIMENT AND RESULTS: The proposed sequence and reconstruction schema was validated by in vivo study. All measurements were performed on a Siemens 3.0T Spectra system equipped with 16-channel head-neck coil. The first measurement used product DW-EPI sequence with the flowing parameters: TE/TR = 78/6000 ms, FoV = 22 x 22 cm, Matrix = 160 x 160, b = 0, 1000 s/mm^2, Repetition = 2, Excitation flip angles of these two repetitions are both 90º. In the second measurement, the modified sequence was used with same parameters except that flip angles of the two repetitions are set to 60º / 120º. Images of this measurement were reconstructed as described above.

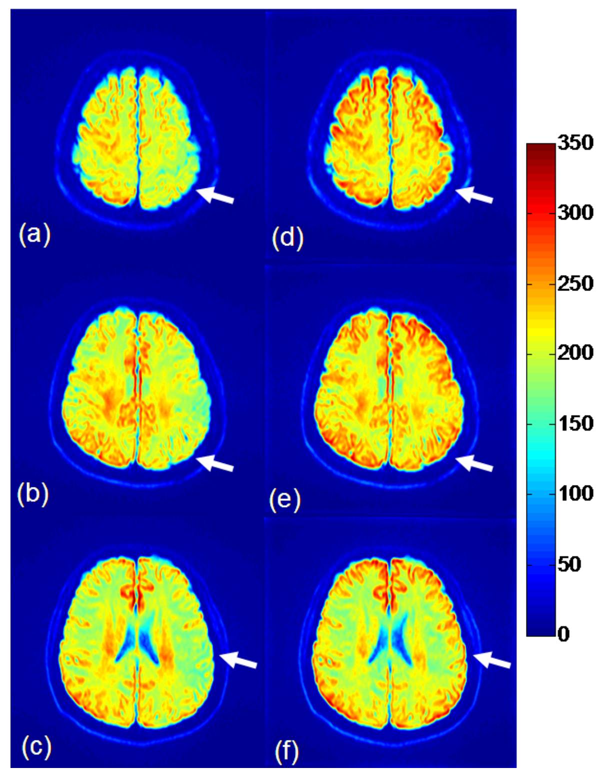

FIG.1. *Three slices acquired with product DWI sequence (a-c) and the corresponding slices measured using the proposed method (d-f).*

Fig.1 shows three slices of original (a-c) and corrected (d-f) DW images with b = 1000. The corrected images demonstrate better signal homogeneity, in particular in the region indicated by the arrows. Furthermore, it is obvious that we have also remained the intensity variations of gray matter across the whole slice as well.

DISCUSSION AND CONCLUSIONS: In high-filed MRI, DWI image quality might be negatively impacted by B1 inhomogeneity. The proposed DW-EPI sequence uses a build-in B1 mapping method to provide B1 inhomogeneity information without any additional time cost. This information is then applied in the post-processing to improve image symmetry and uniformity.

REFERENCE: [1] Hornak et al. Magn Reson Med 6:158-163. [2] Cunningham et al. Magn Reson Med 55:1326-1333. [3] Sacolick et al. Magn Reson Med 63:1315-1322. [4] Wang et al. Magn Reson Med 53:408-417.