Evaluation of MR Image Intensity Inhomogeneity Correction Algorithms

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INTRODUCTION

MR image intensity inhomogeneity has rendered quantitative MRI analysis in anatomical studies a major challenge because most conventional analysis procedures are based on the assumption that voxel intensities are the same for a given tissue. Various methods for performing inhomogeneity correction have been proposed, including SPM [1], N3 [2], FSL [3] and the field map method [4]. Evaluation of these methods has often relied on subjective assessment because of the lack of the ground truth for in vivo data. Using simulated or synthetic data for evaluation is also not satisfactory because such data generally contain limited or unrealistic anatomical information. In this abstract, we present a new method to evaluate MR image intensity inhomogeneity correction methods based on both uniform phantom and in-vivo brain images. Particularly, the ground-truth from the phantom is used for quantifying the performance of the intensity inhomogeneity correction algorithms. The method was applied to four popular inhomogeneity correction procedures. We found that the field map method outperformed the others. The proposed evaluation method can be used to guide parameter optimization for existing correction methods, improve bias field modeling, and evaluate and optimize new correction methods.

METHODS

MRI scans of ten normal volunteers and a uniform phantom were acquired on a 3.0 T Siemens Trio-Tim system with a Siemens 12 channel head coil. The imaging images of the phantom were carried out using a gradient echo sequence with the following parameters: FOV 14 cm; matrix 128x128; Slice thickness 5 mm; TR/TE 2000/6, flip angles 45°, 80°, and 90°; The images of normal subjects are carried out using a segmented EPI sequence at the parameters of FOV 240x218 mm^2, matrix 128x116, slice thickness 5 mm, TR/TE = 3000/13 ms, flip angles 120° and 60°. A minimal contrast image was obtained at TR/TE =1600/13 ms with a flip angle of 90°. T1-weighted images was acquired using a MPRAGE sequence with the resolution of 0.8 mm^3 at TR/TI/TE=1960/930/4.7 ms.

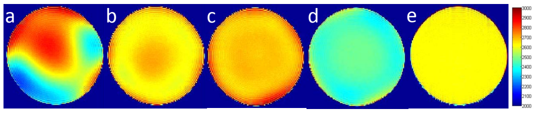

Fig.1. The image of a uniform phantom (**a**) and corrected images using N3 (**b**), SPM (**c**), FAST (**d**) and field map method (**e**).

RESULTS AND DISCUSSIONS

Results on the uniform phantom show that the field map method outperformed N3, SPM and FAST methods (**Fig. 1)**. Severe inhomogeneous signal intensities were observed in the raw image of the uniform phantom (**Fig.1a)**. The corrected images using N3 (**b**), SPM (**c**) and FAST (**d**) greatly improved the uniformity of the raw image. However, these algorithms introduced new artifacts at the center and the boundary of the phantom image. The field map method (**e**), on the other hand, corrected the bias field remarkably and did not introduce any artifacts. The coefficient of variation (*CV*), defined as $CV = \delta / u$, where δ and u are the standard deviation and mean of the signal intensities of a given tissue or uniform region[7], was used to quantify the quality of the images from the various correction methods. The CV of a raw image is 11.9% (Table 1). The field map method reduced CV to 4.0%. Obviously, the 4.0% CV after the correction using the field map method mainly results from the noise.

Fig. 2 shows that T1-weighted images of a human brain (**a**), and the results after it is corrected using N3 (**b**), SPM (**c**), FAST (**d**), and the field map method (**e**). All methods produce reasonable good correction results. Image intensity uniformity of each tissue type was greatly improved. However, the sharp boundaries between white matter (WM) and gray matter (GM) become blurry after N3, SPM, and FAST correction. The smoothed tissue boundaries and edge artifacts could lead to the mis-quantifications of tissue volumes. No tissue boundary blur resulted from the field map correction method. To quantify the quality of the images from the various correction methods, we first obtained binary GM and WM masks using the SPM segmentation algorithm, and then isolated GM and WM regions by multiplying the binary masks with the corrected images. CVs of the isolated WM and GM across the whole brain were computed (Table 1). The results demonstrate that the field method map also outperformed the other methods on the human brain. The residue non-uniformities may come from the following factors: (1) location dependent signal intensities of the same tissues; (2) imperfect inhomogeneity correction, for example, the effect of imperfect inversion recovery is ignored in the field map method; and (3) non-optimal processing parameters.

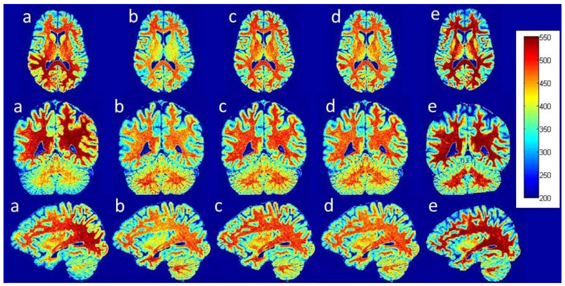

Fig. 2. The image of a human brain (**a**) and corrected images using N3 (**b**), SPM (**c**), FAST (**d**) and field map method (**e**).

CONCLUSIONS

Both phantom and in-vivo human brain experiments were used to qualitatively and quantitatively evaluate four popular MR image intensity inhomogeneity correction methods. The results show that the field map method produced the best performance over N3, SPM and FAST. The proposed phantom validation strategy is more reliable and effective than the validations based on synthetic or simulated images. The proposed evaluation method can be used to guide parameter optimization for existing correction methods, improve bias field modeling, and evaluate and optimize new correction methods.

Table 1 Percent CV of uniform phantom, GM and WM using different bias field correction methods

Method	Phantom	GM	WM
Raw image	11.9	10.7	7.7
N3	7.4	7.9	6.0
SPM	8.0	7.1	5.2
FSL	7.4	7.9	5.0
Field map method	4.0	7.0	4.8

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