Evaluation of Sensitivity Encoded Diffusion Tensor Imaging at 4T

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Introduction

Parallel imaging (PI) based on sensitivity encoding (SENSE) reconstruction has recently been employed for diffusion tensor imaging (DTI) of the brain, resulting in shorter acquisition times and less susceptibility artifacts. However, image quality suffers with high acceleration factors for two reasons: reduced acquisitions and reconstruction imperfections. Previous investigations of the effect of SENSE reconstruction for DTI primarily concerned general signal-to-noise degradation but did not explicitly quantify the systematic effects on DTI. The purpose of this study was to determine the extent to which PI can impact DTI, especially in the context of measuring the topology of age-related alterations of fractional anisotropy (FA) in corpus callosum (CC).

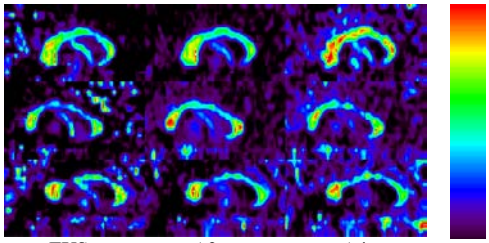

Figure 1. FA maps of corpus collosum of 3 female volunteers of age 35, 51 and 57 years.

Methods

Data Acquisition: 8 health volunteers (mean age 50.9, range 35 to 66 years, 5 males and 3 females) were scanned using a 4 T Bruker MedSpec whole-body scanner. DTI data were acquired using a single-shot echo-planar imaging sequence (matrix 128 x 128 x 18, 1.8 x 1.8 x 3mm resolution, four averages), encompassing the entire CC. Diffusion weighting was encoded along 6 orientations with b_1= 800 mm^2/sec and a reference EPI scan with b_0 = 30 mm^2/sec. The acquisition time per dataset was 2.8 minutes. Data Processing: SENSE reconstruction was performed using a MATLAB program, PULSAR[1] and compared to full *k*-space sampled (FKS) DTI data using sum-of-square algorithm. The reconstructed DTI sets were further processed using DtiMap to obtain FA maps[3,4]. Image entropy was used to characterize texture features of FA maps.[5]. Furthermore, histograms of FA values within the CC regions were evaluated. To determine the effect of SENSE reconstruction on FA values in different regions of the CC regions were modeled as a function of PI acceleration in comparison to FKS reconstruction using a linear mixed-effect model, which treated biological variability among the subjects as a random effects. Methods and regions were treated as fixed effects. Age and gender were also included as covariates. The model was fitted via maximum likelihood to determine if FA variations remained immune to effects from PI accelerations.

Results

Figure 1 shows typical FA maps of CCs from three female volunteers 35, 51 and 57 years with full k-space reconstruction (FKS) and SENSE reconstructed with acceleration factors two (A2) and four (A4). In the CC, this clearly shows increased noise as PI at acceleration A4, resulting in FA overestimations especially in the genu. The statistics showed that PI acceleration altered significantly FA measurements in the genu (p < 0.01) and CSF (p < 0.001) but not in the splenium (p = 0.6). Furthermore, the effects were more drastic for A4 than for A2. Similarly, entropy, which is a measure of uniformity, significantly increased for PI acceleration 4. These results are also summarized in Table 1. Figure 2 shows histograms of FA values in CC from FKS reconstruction (dark), and PI reconstruction with A2 (blue) and A4 (red). This demonstrates broadening of the histograms for A4 and a shift to higher FA values. Figure 3 shows the correlation of mean FA in the genu with age, separately for FKS and PI reconstruction with A2 and A4. This demonstrates that high PI acceleration leads to an underestimation of the age correlation (FKS: r = 0.84, p = 0.004; A2: r = 0.80, p = 0.007; A4: r = 0.68; p = 0.022).

Table 1. FA of genu, splenium and CSF, CC texture entropy from FKS, A2 and A4

	FA values (mean ± SD)			CC Entropy
	Genu	Splenium	CSF	(mean ± SD)
FKS	0.69 ± 1.0	0.88 ± 0.6	0.055 ± 0.007	7.0 ± 0.5
A2	0.67 ± 1.0	0.87 ± 0.7	0.067 ± 0.010*	6.8 ± 0.5
A4	0.74 ± 1.4†	0.88 ± 1.7	0.079 ± 0.008**	7.6 ± 0.5**

* p < 0.05, **p <0.01, †0.1> p > 0.05, all p values are obtained using a linear mixed-effect model .

Discussions and conclusion

As expected, PI reconstruction using SENSE significantly amplified noise, which resulted in a bias of FA measurements towards higher values, particularly with high acceleration factors. It was demonstrated, SENSE reconstruction with an acceleration of 4 altered biologically distinction features, such as correlation of FA in the genu with age. Consistent with the changes of the first order statistics described by the linear mixed model, image texture entropy increased globally when SENSE was used with high acceleration factors. In conclusion, SENSE reconstruction can bias DTI results. The results further emphasize the importance to develop PI reconstruction algorithms for DTI that avoid noise amplification. The approach using the 1st and 2nd order statistics may prove useful as the optimal parameters of the new algorithm are likely not only to depend upon initial SNR, but also quantitation accuracy of DTI measures, such as FA.

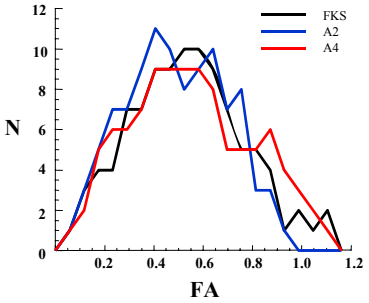

Figure 2. Histograms of voxel FA of CC from FKS, A2 and A4

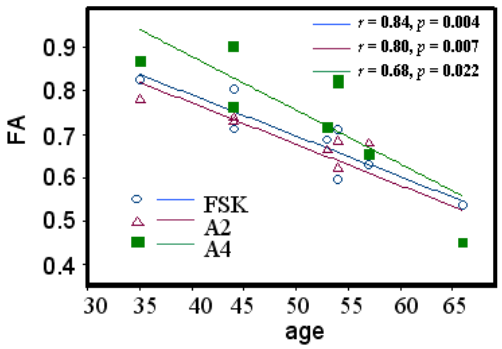

Figure 3. FA of genu plotted against age for FKS, A2 and A4.

References

1) Rane SD and Ji JX. Proc ISMRM 2005, p. 2457. 2) Walsh DO et al, MRM 2000; 43: 682-690. 3) Jiang H et al, mri.kennedykrieger.org. 4) Wakana S et al, Radiology 2004; 230: 77-87. 5) Haralick RM et al, IEEE Trans Syst Man Cybernet 1973; 3: 610-621.