Acceleration strategy for navigated diffusion imaging

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Introduction: Accelerated imaging can be used to very much reduce the amount of spatial distortion present in diffusion-weighted images (e.g., see Fig. 1). An acceleration method is presented here that differs from parallel imaging (PI) and compressed sensing (CS) in several key ways. Because PI benefits from regular (or at least, mostly-regular) down-sampling and CS from randomized down-sampling, combining the two is not trivial and may affect the performance of both. A feature of the proposed approach is that it uses the regular down-sampling schemes typically preferred by PI algorithms, and for this reason is readily compatible with it.

Navigator signal has been used to correct for motion in segmented diffusion imaging [1]. A smooth representation of the object is obtained from a central k-space region, and phase information is used for motion compensation [1] (the magnitude is discarded). On the other hand, smooth images may also be called 'prior knowledge', and can be used for regularization purposes [2]. The magnitude signal in an *x*-*y*-frequency space is used for as part of a regularization term, and phase is discarded. The proposed approach makes full use of navigator data, i.e., both magnitude and phase, in an accelerated segmented acquisition scheme with motion correction.

Method: As usual in accelerated imaging, the problem to be solved can be expressed as: $\mathbf{s} = \mathbf{E} \times \boldsymbol{o}$, (acquired signal = encoding matrix × object). The least-square solution is: $\hat{\boldsymbol{o}} = (\mathbf{E}^H \mathbf{P}^{-1} \mathbf{E}+\lambda^2\mathbf{L})^{-1} \mathbf{E}^H \mathbf{P}^{-1} \boldsymbol{s}$, where $\mathbf{E}^H \mathbf{P}^{-1}$ is a pre-conditioning term and $\lambda^2\mathbf{L}$ is a damped least-square regularization term. In the present implementation, $\boldsymbol{o}$ and $\boldsymbol{s}$ are represented in the x-y-k_b-k_d space, where k_b and k_d are the Fourier transform duals of b and d, the diffusion coefficient and the direction index. The encoding matrix is given by: $\mathbf{E} = \Sigma(\mathbf{F}_d\, \mathbf{F}_b\, \mathbf{F}_y^H\, \mathbf{D}_i\, \mathbf{F}_y\, \mathbf{C}_j\, \mathbf{P}_i\, \mathbf{F}_d^H\, \mathbf{F}_b^H)$, where $\mathbf{F}_y$, $\mathbf{F}_d$ and $\mathbf{F}_b$ perform Fourier transforms along y, b and d, respectively, $\mathbf{P}_i$ is a motion-related phase correction (from navigator data), $\mathbf{D}_i$ subsamples k-space, $\mathbf{C}_j$ is the sensitivity map for coil j, and the summation is made over all interleaved segments i. The regularization matrix $\mathbf{L}$ is diagonal, and navigator data are used to calculate the diagonal elements.

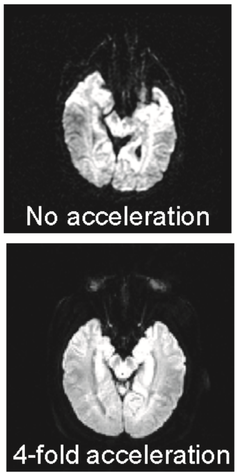

Fig. 1: Accelerated scans show reduced amounts of distortion.

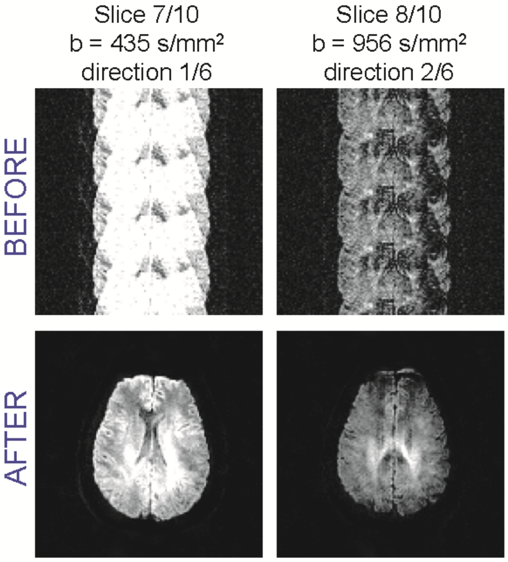

Fig. 2: The acquired data suffered from 4-fold aliasing, which was almost entirely suppressed by the proposed algorithm.

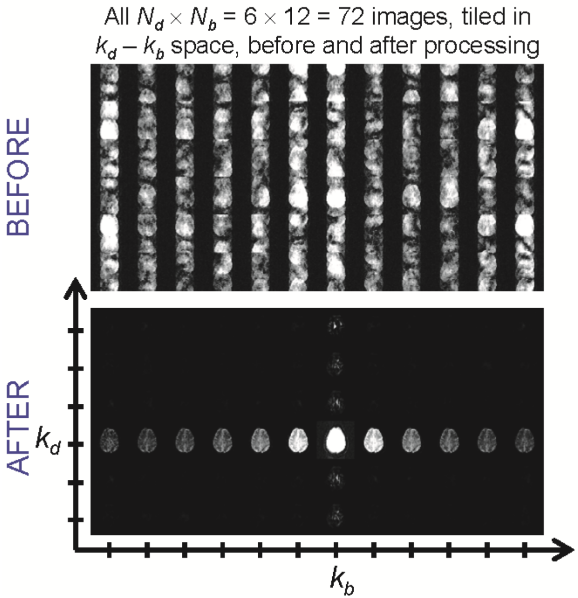

Fig. 3: Data in k_b-k_d space, before and after processing.

Results: Four-fold sub-sampled data were acquired in a healthy volunteer on a 3T system using a navigated EPI sequence (25.6 cm FOV, 4 mm slice thickness, 128×128 matrix size, ±250 kHz, TR/TE = 3s / 76.5ms, 6 directions, $b_{\max}$=2000 s/mm^2, 12 b-values, one fully-sampled T_2-weighted). To emphasize that PI does not contribute to the acceleration obtained here, a quadrature head coil (i.e., single channel) was employed here. As shown in Fig. 2, while the acquired signal $\boldsymbol{s}$ was heavily corrupted by aliasing, the reconstructed signal $\hat{\boldsymbol{o}}$ was mostly free of artifacts. In Fig. 1, a comparison with fully-sampled single-shot EPI demonstrates the effective reduction in distortion. As exemplified in Fig. 3, the main reason why the present approach works well is because diffusion signal tends to be sparse in k_b-k_d space. Calculated fractional anisotropy images are shown in Fig. 4.

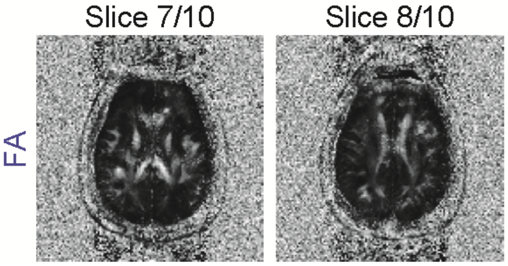

Fig. 4: Calculated fractional anisotropy. While a monoexponential decay was assumed here, other signal models could readily be handled.

Conclusion: An accelerated motion-corrected diffusion imaging method was proposed that makes full use of available navigator data. [1] Atkinson et al. MRM 2006;56:1135. [2] Tsao et al. MRM 2003;50:1031. Support from grant R01EB010195 is acknowledged.