Elimination of DWI signal dropouts using blipped gradients for dynamic restoration of gradient moment

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Introduction

Diffusion weighted imaging (DWI) employs strong gradients to sensitize scans to microscopic molecular motion. However, this inevitably makes DWI sensitive to head movements, which may lead to partial or complete signal loss due to incomplete re-phasing. Prospective motion correction [1,2] can attenuate in-plane and through-plane motion effects. Recently, Herbst et al [3] proposed continuous updating of gradients and RF pulses within each k-space line, and were able to attenuate signal dropouts during faster movements. Here we present an alternative method to eliminate movement-induced signal loss in DWI scans that requires only a single dynamic update of the DWI sequence.

Theory

Modeling the brain / head as a rigid-body object, motion during the acquisition alters both the phase (due to translations) and gradient moment (due to rotations). The trajectory of a spin inside the imaging volume is described by a rotation matrix $R(t)$, translation vector $T(t)$, and initial position x_0 as: $x(t,x_0) = T(t) + R(t).x_0$. It can then be shown that the rotational component of the movement induces an effective gradient moment M as follows: $M = \int_0^t R^{-1}(t).G(t).dt$ [Eq.1].

For a stationary system, the sequence is generally balanced and M=0, but rotations (time-dependent R) induce a gradient imbalance (residual gradient moment ΔM) that can result in signal attenuation or dropouts in the presence of diffusion gradients. Using head motion data from a high-speed optical tracking system, and the known timing and amplitudes of sequence gradients, we eliminate these detrimental effects by calculating ΔM accumulated during the sequence, and applying a small blip gradient of moment –ΔM to restore gradient balance immediately prior to the readout.

Methods

MRI was performed on a Siemens Trio scanner using an EPI-based, twice-refocused DWI sequence (TR=4300 ms / TE=100 ms / resolution 64x64 / voxel size=3.4 x 3.4 x 4.0 mm^3 / b=[0, 1000] / MDDW, 6 diffusion directions). We used a Moiré Phase Target (MPT) [4] based motion tracking system for prospective correction. The tracking system consists of an MR-compatible digital camera mounted inside the bore and a 15x15 mm MPT target attached to the subject's forehead. The camera operated at 60 frame/s, and images were analyzed in real-time to determine changes in head pose (3 translations and 3 rotations, lag time ~30 ms). The DW-EPI sequence [5] was modified to receive MPT feedbacks before the excitation and the readout per slice. The first feedback was used to update the slice position to correct for inter-slice motion (Fig. 1). Additionally, tracking packets (typically 5) were received between excitation and readout, and the rotation matrices were used to calculate the residual gradient moment ΔM by numerical integration of Eq.1. A blipped gradient of moment -ΔM (200μs duration) was inserted immediately prior to the readout (Fig. 1). Two healthy, consenting volunteers performed intentional head movements during two DWI scans, with and without the proposed gradient moment correction.

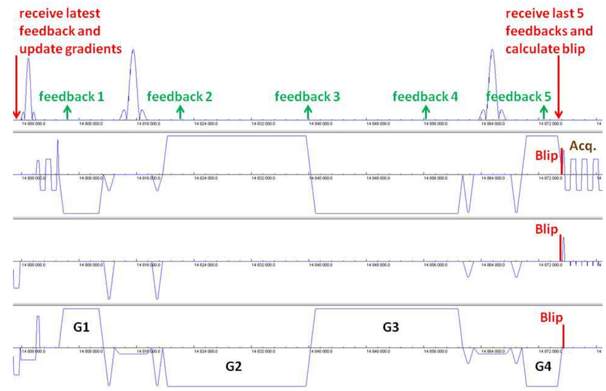

Fig. 1. Diagram of modified DWI sequence: tracking feedback (green arrows) is read twice (red). Sequence orientation is updated initially, and a blip gradient is updated immediately before readout (as per Eq. 1).

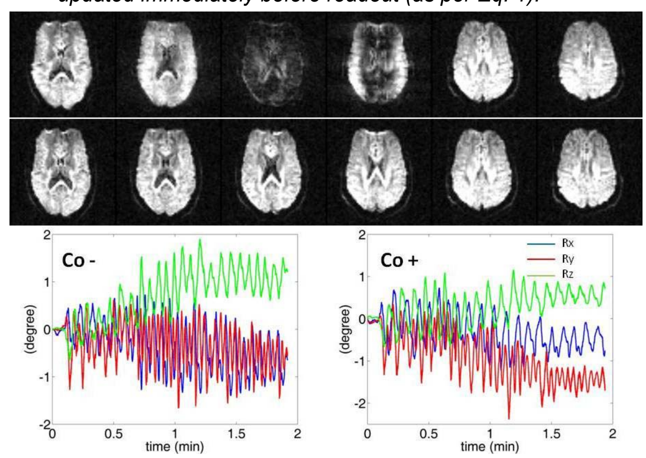

Fig. 2. The images from the uncorrected (1st row) and corrected images (2nd row) and rotation trajectories during the uncorrected and corrected scans (3rd row, left & right)

Results

Fig. 2 shows data from one subject who continuously drew a figure-of-eight pattern with the tip of his nose (in-plane as well as through-plane motion). Signal dropouts occur in two of 6 slices when the gradient moment correction was OFF (top row). However, when the gradient moment correction was ON, no signal losses were observed in any of the diffusion volumes (second row in Fig. 2). The amount of rotational motion was comparable between the two scans (bottom graphs in Fig. 2).

Discussion

We present a new method to correct for signal dropouts in DWI, by dynamically restoring (balancing) the sequence gradient moment. The main advantage of the approach is that the modification to the pulse sequence is relatively minor (inserting a blip gradient immediately prior to data readout), and should be feasible on most modern scanner platforms. Signal loss due to misalignment of the excitation and refocusing pulses is still possible. Our results demonstrate the potential of fast prospective motion tracking and correction in terms of desensitizing (DWI) MRI to head movements.

References: [1] Aksoy M et al, MRM, 2010 [2] Benner T, MRM 2011 [3] Herbst M et al, ISMRM, 2011 (170). [4] Andrews-Shigaki, BC et al., JMRI, 2010. [5] Reese T et al, MRM, 2003

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