Clinical feasibility of high-resolution single-shot diffusion tensor trace -weighted (ssTW) MRI

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Introduction: The mean apparent diffusion coefficient (ADC) is a diffusion tensor imaging (DTI) -derived quantity (1) which has had a significant clinical impact uniquely characterizing tissue microstructural changes during stroke and cancer. Since the mean ADC is derived from the trace of the diffusion tensor calculated using separately acquired diffusion-weighted images (DWI) with different diffusion-weighting orientations, it is prone to bias due to subject/physiological motion induced image misregistration and partial volume effects. To address these limitations, almost two decades ago, several techniques were proposed to achieve mean ADC weighting in a single scan (2, 3). Preliminary attempts to translate these methods to the clinical arena (3, 4, 5) suffered from poor spatial resolution and limited signal-to-noise ratio (SNR) due to the impractically long echo times (TE) >150ms required by the use of the weak diffusion gradients available at that time and the lack of parallel imaging. In light of the clinical impact that the mean ADC has had in the last decade, here we revisit the feasibility of quantifying this important clinical parameter in a single scan and propose an optimized and efficient solution for whole-brain high-resolution single-shot diffusion tensor trace weighted (ssTW) MRI that could potentially enable rapid mean ADC mapping for brain and whole-body MRI applications where motion is problematic i.e., infant populations.

Methods: We modified the single scan TW method proposed by Mori and van Zijl (2) to minimize the TE and accommodate a long EPI readout duration. The full k-space acquisition enables the use of large imaging matrix size and increases the robustness of the measurement to the commonly observed motion-induced signal loss artifacts (6). The pulse sequence (Fig. 1) was implemented on a clinical GE 3T scanner equipped with 5 G/cm/axis gradients, and was used to scan healthy volunteers. Using a diffusion gradient pulse duration δ=7ms, it is possible to achieve a b-value of 750 mm²/s with TE=105 ms and whole-brain coverage within a TR=15 ms. Images were acquired with a 3 mm slice thickness and 1.5 mm in-plane resolution (144x144 matrix size over 220x220 mm² field-of-view (FOV), SENSE acceleration factor of 2). To evaluate the effects of eddy current distortions on the image, additional TW images were obtained with the polarity of the diffusion gradients flipped on each axis. For comparison, the mean ADC was also measured using conventional DTI with the same scan parameters, but 20 DW orientations, and a TE=82ms.

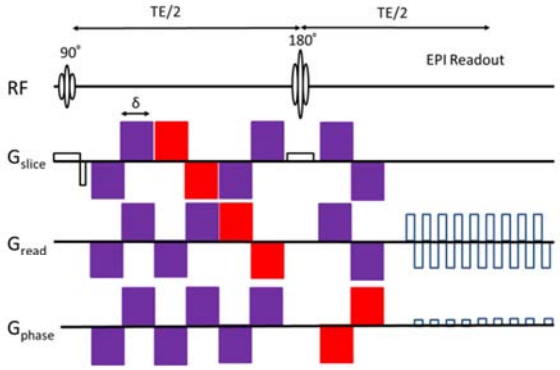

Figure 1: Pulse sequence for ssTW MRI: the series of positive (purple) and negative (red) bipolar gradients results in cancelling contributions from off-diagonal diffusion tensor elements to the DW signal.

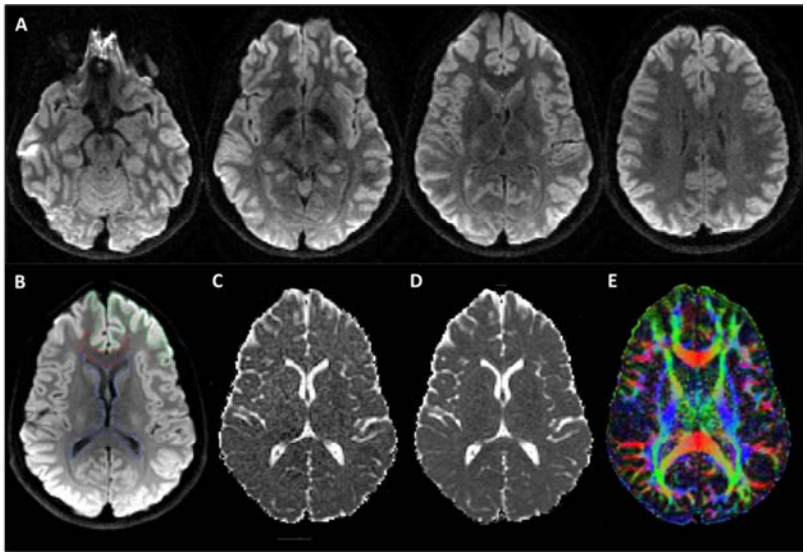

Figure 2: **A.** Trace weighted MRIs acquired using our ssTW method in 15s across the entire brain. **B**. Brain tissue regions-of-interest (ROIs) **C**. Mean ADC map calculated from the ssTW scan. **D.** Mean ADC map calculated using DTI with 20 directions in 2 min. **E.** Direction-encoded color (DEC) fractional anisotropy map derived from the DTI scan.

Results and Discussion: High-resolution DWIs obtained using the proposed single-shot trace weighted (ssTW) method showed good SNR and uniform white matter diffusion contrast with no fiber-orientation dependence (Fig 2, A and B). ssTW images acquired with different gradient polarities showed similar mean ADC values throughout the brain and negligible image distortions suggesting that gradient eddy currents do not significantly affect diffusion quantitation or spatial distortions. Mean ADC images measured using ssTW (Fig. 2C) in gray matter, white matter and cerebrospinal fluid ROIs (1.08 μm²/ms, 0.86 μm²/ms, and 1.82 μm²/ms respectively) were similar to those derived with conventional DTI (Fig. 2D) (1.10 μm²/ms, 0.83 μm²/ms, and 2.01 μm²/ms respectively), despite the significantly shorter acquisition time.

Conclusion: Our results demonstrate that using up-to-date gradient technology and parallel imaging it is possible to acquire, within a few seconds, high-resolution ssTW MRIs with whole brain coverage. Upon clinical validation, this technique could provide fast and accurate assessments of microstructural changes during stroke or tumor progression. Most importantly, ssTW MRI could be uniquely suited for high-resolution mean ADC mapping in whole-brain or whole-body MRI applications where subject motion is unavoidable, i.e. imaging brain development in infants, or fetuses *in utero* within a single breath-hold of the mother (7).

References: 1. Basser et al., Biophys J 1994;66:259-267; 2. Mori and van Zijl, MRM 1995;33:41-52; 3. Wong et al., MRM 1995;34:139-143; 4. Chun et al., MRM 1998;40:622-628; 5. Cercinangi and Horsfield, JMR 199;140:58-68; 6. Freidlin et al., JRM 2012;221:24-31; 7. Kim et al., MRM 2008;59:216-220.