In Vivo Spin Echo EPI Cardiac Diffusion Tensor MRI Using Ultrahigh Gradient Amplitudes

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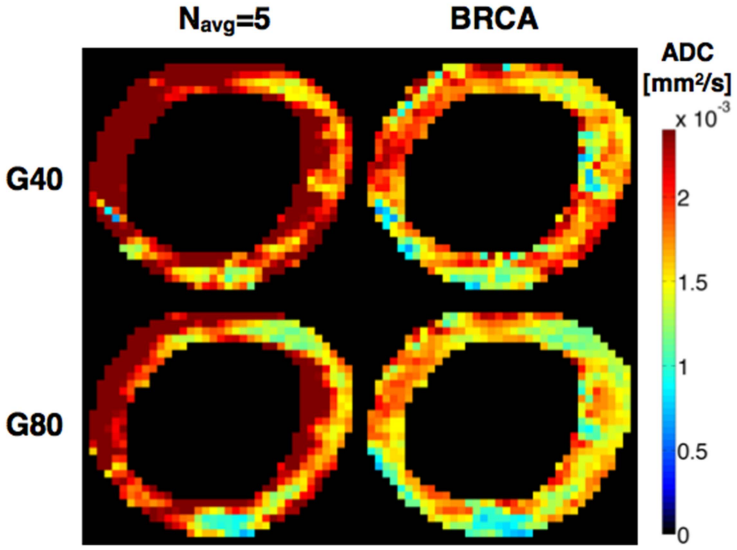
PURPOSE: To improve the robustness to bulk motion of spin-echo single-shot EPI (SE-EPI) cardiac diffusion tensor MRI (DTI) by using ultrahigh maximum gradient amplitudes (G_{max}) and a biophysical reconstruction constraint algorithm (BRCA).

INTRODUCTION: Cardiac bulk motion makes reliable *in vivo* cardiac diffusion-weighted MRI extremely challenging. Diffusion preparation and subsequent imaging can be ECG gated to the diastolic quiescent interval, but this interval is often short and not necessarily free of bulk motion, which leads to bulk motion induced signal dropouts. Recent developments in gradient hardware that permit G_{max}=80mT/m can reduce the temporal footprint of diffusion encoding (t_{prep}) at clinically relevant b-values and enable reconsideration of SE-EPI DTI in the heart[1]. Coupled with hardware advances, further improvements can be made using judicious reconstruction techniques. For example, temporal maximum intensity projection (TMIP)[2] improves measurements of diffusion in the presence of bulk motion. Herein, we propose and evaluate a new biophysical reconstruction constraint algorithm (BRCA).

METHODS: *Image Acquisition* - Healthy, consenting volunteers (N=7) were imaged on a 3.0T scanner (Siemens Prisma) in compliance with the local IRB. ECG gated cardiac DTI (12 directions) were acquired using single shot SE-EPI in a single breath hold. Diffusion was encoded using monopolar gradients with G_{max}=40mT/m (G40) and G_{max}=80mT/m (G80). The b-value remained constant for both cases (b=300mm^2/s) which necessitated different echo times (TE) for each sequence (TE_{G40}=45ms, TE_{G80}=35ms) due to differences in t_{prep} ($t_{prep,40}$=35ms,$t_{prep,80}$=25ms). All other scan parameters were kept constant (resolution: 2.4x2.4x8.0mm, bandwidth: 2000Hz/pixel, 5/8 Partial Fourier). Each acquisition was repeated to improve SNR (N_{avg}=5). *Image Reconstruction* - Motion corrupted signals were discarded by the BRCA prior to tensor reconstruction by first calculating the projection of the apparent diffusion coefficient (ADC) along each diffusion encoding gradient direction from the diffusion weighted and non-diffusion weighted (b_0) signals within each voxel (ADC'). If ADC' exceeded that of free water (D_{H20}=2.4x10^{-3}mm^2/s at 37ºC) plus a two-standard deviation noise contribution estimated from a Rician fit to noisy signals, then it was discarded as corrupted by bulk motion. The diffusion tensor was then reconstructed if the remaining number of diffusion weighted signals was >6 and these directions had acceptable angular dispersion (condition number<4)[3]. *Tensor Comparisons* - Robustness to bulk motion was quantified for G40 and G80 acquisitions by the percentage of myocardial voxels discarded by the BRCA. Mean ADC and fractional anisotropy (FA) were also compared in the left ventricular (LV) myocardium.

RESULTS: Figure 1 shows the improved ADC maps obtained from G80 compared to G40 acquisitions and the further gains with BRCA. As expected, the ADC (Fig. 1 and Table 1) and FA (Table 1) are lowest for G80-BRCA (i.e. less bulk motion corrupted). The percentage of discarded LV voxels with ADC'>(D_{H20}+noise) (motion corrupted) decreased in all subjects for G80 compared to G40 (Table 1). G80+BRCA offers more accurate quantification and produces a more homogeneous ADC map.



	G40 MONO	G80 MONO
ADC'>D_{H20}	60±18%	44±25%
ADC (x10^{-3}mm^2/s)	2.02±0.6	1.96±0.5
FA	0.64±0.2	0.62±0.2

Table 1. Percentage of voxels rejected by biophysical reconstruction constraint algorithm (top row) and mean global ADC and FA values in LV myocardium.

Figure 1. Typical ADC maps (mm^2/s) of the LV using signal averaging (left column) and the proposed biophysical reconstruction constraint algorithm (right column) using G_{max}=40mT/m (top row) and 80mT/m (bottom row). Deep red indicates voxels where ADC>(D_{H20}+noise).

DISCUSSION: Bulk motion artifacts manifest as large signal dropouts in DWI that lead to artificially high ADC estimates. The prevalence of ADC>(D_{H20}+noise) is thus indicative of motion corruption in a particular acquisition. By this metric, the bulk motion robustness of G80 was improved compared to G40 as a consequence of its shortened diffusion preparation. This indicates that with newly available gradient hardware, cardiac DTI using SE-EPI may be a viable alternative to the more widely used Stimulated Echo Acquisition Mode (STEAM)[4] approach while avoiding the need for strain correction and delivering better SNR performance.

CONCLUSION: Shorter diffusion preparation times made possible with ultrahigh G_{max} gradients (G80) combined with a biophysical reconstruction constraint algorithm (BRCA) improved the robustness to bulk motion of cardiac DTI.

REFERENCES: **1**. Gamper, U. *MRM* 2007; 57: 331-337 **2.** Rapacchi, S. *Invest Radiol*, 2011; 46(12): 751–758 **3**. Skare, S. *JMRI*, 2000; 147: 340-352 **4.** Dou, J. *MRM*, 2002; 48: 105-114

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