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Increased maximum gradient amplitude improves robustness of spin-echo cardiac diffusion-weighted MRI

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Background

Cardiac motion presents a major challenge in diffusion weighted MRI (DWI), often leading to large signal drop-outs that necessitate repeated measurements (Pai, V.M., *MRM* 2011). While cardiac DWI is generally ECG gated to apply diffusion weighting during peak-systole or end-diastole, these intervals can be short and difficult to pin-point, resulting in poor sequence reproducibility.

Recent improvements in gradient hardware provide larger maximum gradients than current systems (G_{max}=80mT/m), which can substantially reduce the temporal footprint of diffusion preparation and make cardiac DWI more robust to bulk motion.

Methods

A left ventricular (LV) motion model simulated motion of the healthy heart with 30-70ms quiescent intervals (t_Q). Monopolar encoded SE-DWI (b=500 s/mm^2, 3 directions) was simulated using: G_{max}=40 and 80mT/m with diffusion gradients centered at mid-quiescence and with a range temporal offsets (ΔT=±20ms). Complex Gaussian noise was added such that SNR=50 for b=0 images. Bulk motion induced error was measured by the bias in apparent diffusion coefficient (ADC) recovery from the programmed value (ADC=1x10^{-3} mm^2/s). Sequences that recovered ADC with bias<10% for ΔT=±10ms were deemed robust to motion.

Three healthy volunteers were scanned in a 3.0 T Siemens Prisma (Gmax=80mT/m) scanner using breath hold cardiac DWI (12 directions, monopolar encoding, single-shot SE EPI readout). Five repetitions of each sequence were acquired: 1) G40-b300: G_{max}=40mT/m, b=300 mm^2/s, TE=44ms; 2) G40-b100: G_{max}=40mT/m, b=100mm^2/s, TE=36ms; and 3) G80-b300: G_{max}=80mT/m, b=300 mm^2/s, TE=36ms. Imaging was timed to the diastolic quiescent interval, which was determined visually from CINE images.

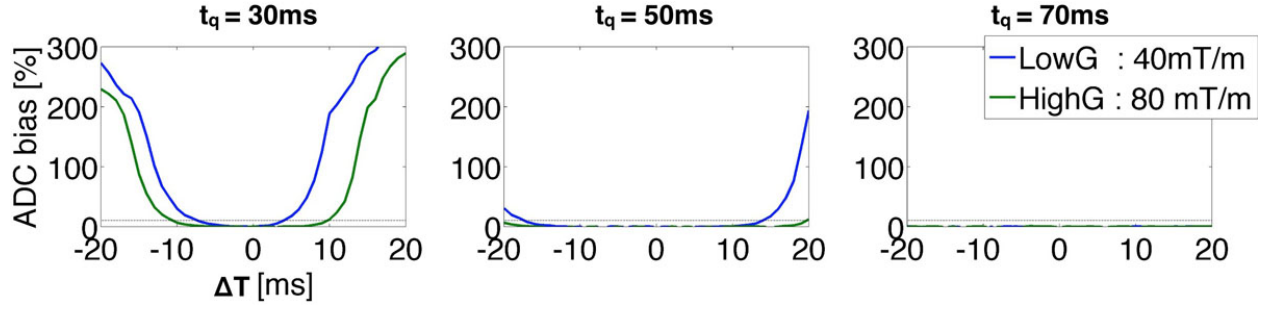

Figure 1 Percent ADC Bias vs. ΔT (temporal offsets) for different tQ (quiescent interval) for b-value=300 s/mm^2. G80-b300 can provide acceptably small ADC bias for t_q≥30ms, but G40-b300 requires t_q≥50ms.

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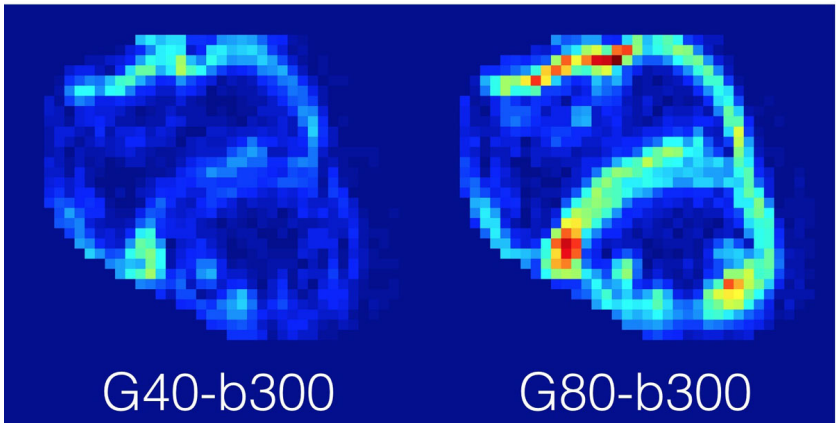

Figure 2 Typical DWI from G40-b300 (left) and G80-b300 (right). Image quality was generally better for G80-b300.

Two observers evaluated the quality of all images as: "acceptable"-no significant signal dropouts in myocardium or "unacceptable"-significant signal dropouts, and directly compared G40-b300 to G80-b300 (fixed b-value).

Results

The simulated ADC bias (Fig. 1) shows that G80-b300 can provide acceptably small ADC bias for $t_q \geq 30$ms, but G40-b300 requires $t_q \geq 50$ms.

Image quality was better in G80-b300 than G40-b300 in 86% of images (example pair shown in Figure 2). 55% of G80-b300 images were acceptable, whereas 30% of G40-b300 and 70% of G40-b100 were.

Conclusions

Simulations show that G80 recovered ADC more accurately than G40 for all t_Q and ΔT and was robust to motion for $t_Q \geq 30$ms. This is likely due to the shorter diffusion preparation (G40 t_{prep}=39ms, G80 t_{prep}=28ms) and indicates that G80 will perform more consistently for short t_Q (fast heart rates, systolic imaging) or changes in heart rhythm.

With fixed b-value=300mm^2/s in vivo, G80 had consistently better image quality than G40. In agreement with simulation, this indicates that G80 improves the robustness of cardiac DWI for the same b-value. With fixed TE=36ms, G40-b100 was acceptable more frequently than G80-b300, but with insufficient diffusion weighting. Increased G_{max} can thus improve diffusion sensitivity with less loss of robustness.

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