Improved Q-Ball imaging using a 300 mT/m human gradient

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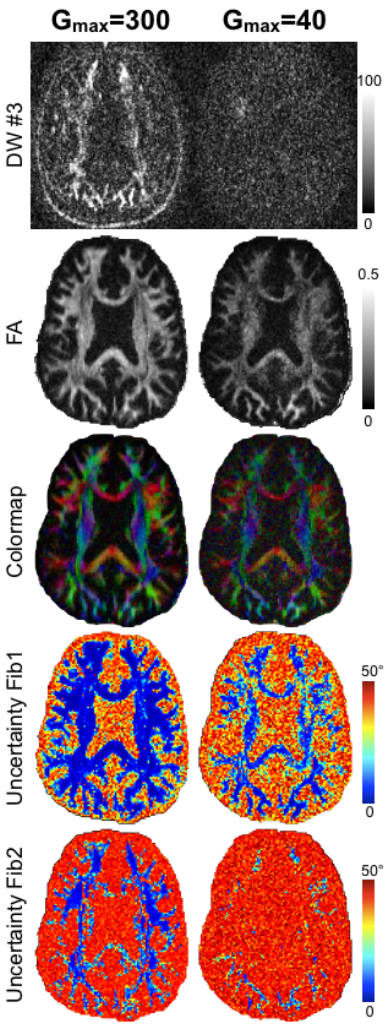
Introduction. The ability to depict white matter microstructure using high angular resolution diffusion imaging (HARDI) is limited by the SNR of diffusion-weighted images and by the gradient strength in current clinical systems. Limited gradient strength results in a long TE at high b-values and considerable loss of SNR due to T_2 dephasing. Thus, while a higher b-value, in principle will encode higher detail in the orientation distribution function (ODF), this has not been possible due to the reduced SNR at higher b-value. In this work we use a new gradient system specifically designed to achieve ultra-high gradient strength (Gmax = 300 mT/m , about 7.5 fold stronger than clinical scanners) to shorten the diffusion-encoding gradient and thereby decrease the echo time (TE), yielding significant gains in SNR. In addition, we developed a 64-channel receive array coil to further increase the SNR. We compare the *in vivo* HARDI data with Q-Ball reconstruction at variable gradient strengths and b-values up to 15000 s/mm^2 in human. The higher SNR is shown to provide improvements in ODF metrics such as the fiber uncertainty and FA.

Methods. *Acquisition*. A volunteer was scanned on a 3T MRI system (MAGNETOM Skyra, 64 receive channels, Siemens Healthcare, Germany) equipped with a *Connectom Gradient* (AS302†) system capable of up to 300 mT/m and slew rate of 200 mT/m/ms. The slew rate was derated during the diffusion encoding to prevent physiological stimulation. A custom-made 64-channel phased array coil was used for signal reception. We compared two datasets acquired with a single-refocusing EPI sequence: 1) b=10000 s/mm^2 Q-ball with G_{max}= 300 mT/m allowing a TE of 51 ms and 2) the conventional Gmax=40mT/m providing a minimum TE of 117 ms. Common parameters were: TR=3000ms, 20 slices, FOV=220, partial Fourier=6/8, R=3 (with GRAPPA), 1.5mm isotropic, b=10000 s/mm^2, 200 directions (electrostatic repulsion), BW=1902 Hz/pix, echo spacing = 0.63. Additionally, we compared different b-values of b=1000 (TE=46ms), 5000 (TE=51ms), 10000 (TE=51ms) and 15000 s/mm^2 (TE=54ms) at Gmax=300 mT/m. *Processing*. Data were corrected for motion (along with the b-matrix) using b=0 images interspersed every 15 volumes. All datasets were co-registered to allow direct comparison. Diffusion tensors and 95% angular uncertainty of the first and secondary directions were obtained using FSL BedpostX [1]. Q-Ball ODF were reconstructed using spherical harmonics [2] of order 6 (regularization parameter = 0.006, no sharpening applied).

Results. Figure 1 shows diffusion tensors and uncertainty measures for G_{max}=40 and 300mT/m for a b-value of 10000 s/mm^2. The 300mT/m dataset shows lower uncertainty of the first and secondary directions. Figure 2 shows increased robustness and accuracy of the ODFs at 300mT/m. Figure 3 compares Gmax=300mT/m data acquired at b-values ranging from 1000 to 15000 s/mm^2. Improvement of the b=10000 over b=1000/5000 could be seen on the 2nd row, where a secondary direction is better depicted. At b=15000 a third direction appears (middle row), although it remains unclear if this is genuine fiber architecture or artefactual noise contribution.

Discussion. This study presents the first *in vivo* human diffusion-weighted data acquired at G_{max}=300 mT/m. In comparison with the clinical systems, these gradients enable a significant reduction in TE providing substantial gain in SNR and improved Q-ball reconstruction. At b=10000 s/mm^2, TE is reduced by 66ms, corresponding to 2.3× SNR increase (assuming T_2 of 80 ms). Higher b-values yielded higher angular resolution as predicted by theoretical models [3].

† *Works in Progress. The information about this product is preliminary. The product is under development and is not commercially available in the U.S. and its future availability cannot be assured.*



→ Figure 1. *Diffusion-weighted image and DTI/uncertainty measures for G_{max}=300 and G_{max}=40 for a b-value of 10000 s/mm^2.*

References. [1] Behrens, T.E., et al., *Magn Reson Med*, 2003. **50**(5): p. 1077-88. [2] Descoteaux, M., et al., *Magn Reson Med*, 2007. **58**(3): p. 497-510. [3] Cho, K.-H., et al., *Neuroimage*, 2008. **42**(1): p. 262-71.

Achnowledgments. Study funded by the NIH Blueprint for Neuroscience Research: U01MH093765, NIH NCRR P41 RR14075, NIBIB R01EB006847 and National MS Society [FG1892A1/1].

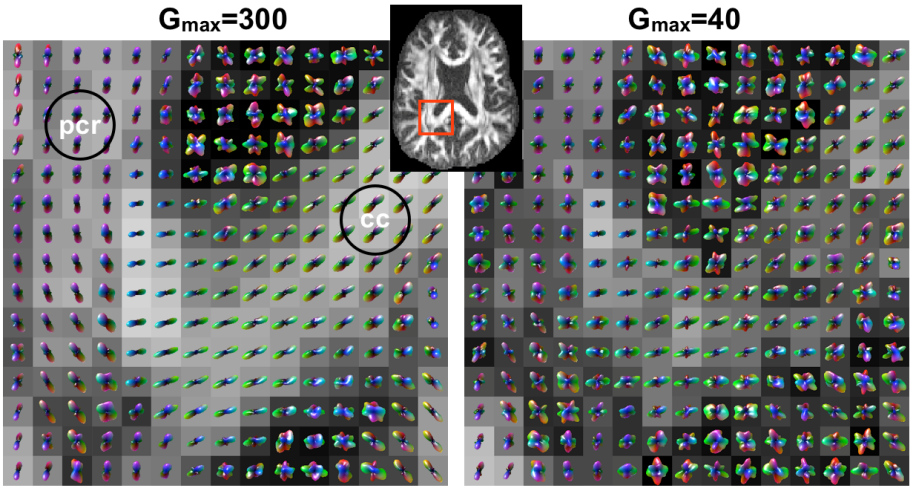


Figure 2. ODFs overlaid on the GFA over the corpus callosum (cc) and posterior corona radiata (pcr). Data acquired with G_{max}=300 mT/m provides more accurate and robust ODFs.

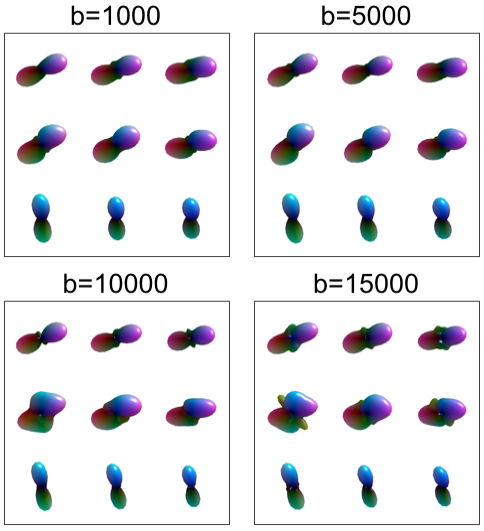


Figure 3. ODFs centered at the intersection between cc and pcr for b-values ranging from 1000 to 15000 s/mm^2 acquired with G_{max}=300 mT/m.