Improving SNR in high b-value diffusion imaging using G_{max} = 300 mT/m human gradients

Introduction In Stejskal-Tanner diffusion-weighted imaging (DWI) [1], the minimum TE is limited by a combination of the EPI readout prior to recording the center of k-space and the duration of the diffusion-encoding gradient lobes. A gradient system that improves upon standard clinical gradients by introducing a higher maximum amplitude provides the possibility of substantially shortening TE. This increases the signal to noise ratio (SNR) by reducing the amount of T_2 dephasing. At high b-values, the diffusion encoding gradient lobes occupy a higher fraction of the TE period and force TE to exceed T_2 (~75ms for white matter at 3T) [2], thus increasing the potential for improving SNR with increased gradient strength. We evaluate the SNR gains achieved with a novel human gradient system employing G_{max}= 300 mT/m and slew rate 200 T/m/s for high b-value HARDI type human experiments through phantom and *in vivo* investigations.

Methods Imaging was performed using a novel gradient system, model AS302, part of a new 3 T system (MAGNETOM Skyra CONNECTOM†, Siemens Healthcare, Erlangen) with bore diameter of 56cm. Two imaging studies, one with a phantom and one with a human subject were performed to assess SNR in DWI.

Following [3], our phantom was composed of polyethylene glycol with molecular weight 400 (Sigma-Aldrich). This material is liquid at room temperature with T_2 = 85 ms and was poured into a 15 cm plastic sphere. Diffusion imaging on the phantom was performed using the MAGNETOM Skyra 20-channel head/neck coil. Images were collected using the standard Siemens implementation of Stejskal-Tanner diffusion encoding (single 180 pulse) with 2D EPI readout, with the addition of a small modification to select the maximum amplitude used in the diffusion lobes. The EPI had imaging parameters: FOV 208 mm, 2mm in-plane resolution, 6/8 partial-Fourier acquisition, and bandwidth of 2185 Hz/px resulting in 14 ms of EPI readout before TE. A single 10 mm slice with TR of 5 s was used to increase the SNR at high b-value. The permutations of b and G_{max} used, and their resulting minimum TE are given in Table 1. The slew rate was de-rated from the maximum 200 T/m/s during the diffusion pulses to allow operation under the peripheral nerve stimulation and IEC cardio thresholds. Similarly, the EPI readout used conventional gradient amplitudes and slew-rates. The SNR was evaluated in a central ROI and compared to its value at G_{max}= 40 mT/m (conventional clinical gradient strength). Additionally, each slice was acquired once with no diffusion encoding lobes (giving a b ~ 0 s/mm^2 image), but keeping TE and other sequence parameters exactly the same as acquisitions with gradient lobes enabled. The same ROI-based comparison was applied to this data.

Phantom b=20000 s/mm^2 Gmax/TE	Phantom b=10000 s/mm^2 Gmax/TE	Human b=20000 s/mm^2 Gmax/TE	Human b=10000 s/mm^2 Gmax/TE
40 / 149	40 / 125	40 / 142	40 / 115
90 / 99	90 / 85	80 / 95	80 / 79
120 / 88	120 / 76	200 / 62	100 / 78
150 / 80	150 / 70	300 / 55	200 / 53
180 / 75	180 / 67		300 / 48
210 / 72	210 / 64		
240 / 69	240 / 63		
270 / 68	270 / 61		
300 / 67			

Table 1. Gmax (mT/m) / TE (ms) pairs imaged for each b-value in phantom and human studies.

Data with one human subject was collected at b = 20000 s/mm^2 and 10000 s/mm^2 with a single z-axis diffusion direction and range of G_{max} values. In each case b ~ 0 s/mm^2 images with no diffusion encoding lobes were also acquired with matched TEs. The sequence was similar to that described above for phantom imaging, but with 2.5 mm isotropic resolution, FOV 240 mm, 5 slices, 2x GRAPPA acceleration, bandwidth 2265 Hz/px, and TR 3 s with 6.4 ms of EPI readout before TE using a custom-built 64-channel head coil. Similar to the phantom experiment, the ratio between each G_{max} and the baseline 40 mT/m were computed in masked regions where white matter was bright in the high-b images at G_{max} = 300 mT/m. This high SNR ROI was chosen to minimize magnitude noise bias in the calculated ratio.

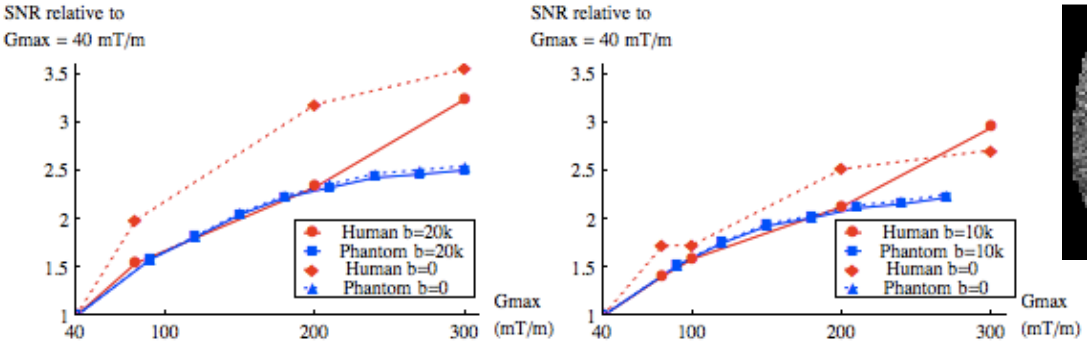

Figure 1. Relative increase in SNR with increasing G_{max} in human (red) and phantom (blue). Left and right plots show b=20000 s/mm^2 and 10 ks/mm^2 respectively. Solid lines are high-b scans, dotted lines are b ~ 0 scans with matched TE.

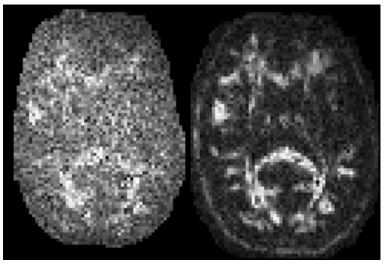

Figure 2. Matched slice from b = 20000 s/mm^2 scan with G_{max} = 40 mT/m (left) and 300 mT/m (right). Pixel intensities mapped so that 0 is black and max/2 is white.

Results Results of the human and phantom experiments are plotted in Figure 1. The solid lines in each plot show the data for the high-b scan, while the dotted lines are the b ~ 0 scans with TE matched to high-b. Each sub-plot shows the results for both the phantom and human experiments at a given b-value. In the phantom the median ratio over the center of the phantom is plotted. In the human, the median ratio over the white matter mask is plotted. In Figure 2 we show matched slices (masked to include only the head) acquired with G_{max}= 40 mT/m and 300 mT/m to demonstrate the improvement in SNR of high-b diffusion scans.

Conclusions The results of the phantom experiment show close agreement between SNR improvement with and without diffusion-encoding gradient lobes, indicating that there is no loss of SNR due to side effects of the high amplitude gradient lobes. In human experiments (where TE is slightly shorter) we see a similarly positive results, indicating a greater than 3x improvement in SNR both in b ~ 0 and 20000 s/mm^2, and a more than 2.5x improvement at b = 10000 s/mm^2.

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References [1] P. J. Basser, J. Mattiello, and D. LeBihan, "Estimation of the Effective Self-Diffusion Tensor from the NMR Spin Echo", J Magn Reson 1994;103:247-54 [2] C. Laule, E. Leung, D. K. B. Li, A. L. Traboulsee, D. W. Pay, A. L. MacKay, and G. R. W. Moore, "Myelin water imaging in multiple sclerosis: quantitative correlation with histopathology" Multiple Sclerosis 2006;12:747-53 [3] W. M. Spees, N. Buhl, P. Sun, J. J. H. Ackerman, J. J. Neil, and J. R. Garbow, "Quantification and compensation of eddy-current-induced magnetic field gradients", J Magn Reson 2011:212:116-123

† 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 ensured.