Improving high-resolution Q-Ball imaging with a head insert gradient: Bootstrap and SNR analysis

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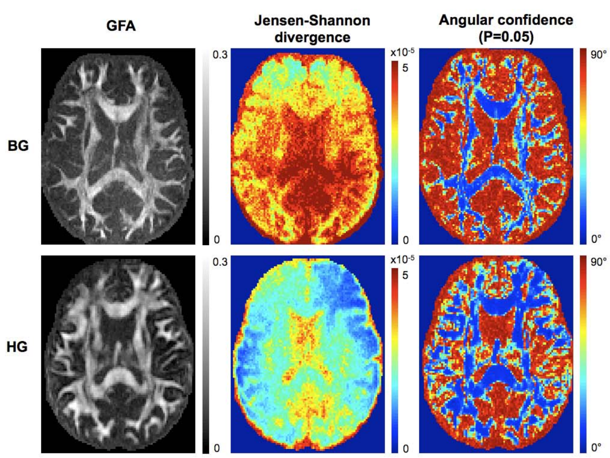
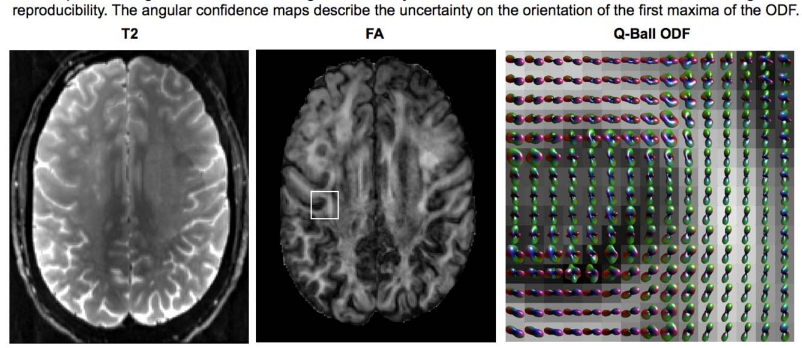
Introduction. The ability to depict small structures of the central nervous system using diffusion-weighted (DW) magnetic resonance imaging (MRI) is notably limited by the spatial resolution and sensitivity of the diffusion-encoded images. However, voxels smaller than ~6 mm^3 (1.8mm isotropic) are difficult to achieve in conventional clinical scanners given the limited signal-to-noise ratio (SNR) of DW images and the amount of susceptibility artifacts when using single-shot acquisitions with a large matrix. A head insert gradient provides higher maximum gradient strength (2x than the regular system), higher slew rate, higher duty cycle and does not induce B0-drift. Using a head insert diffusion-encoding gradient areas can be achieved in less time and read-outs can be shortened thereby decreasing the echo time (TE) and yielding significant gains in SNR for comparable b-values. Additionally, the faster EPI readout reduces susceptibility distortion. Although head gradients have been used previously [1], they have not been combined with highly parallel detection (32ch receive coils) since many RF coils do not fit in the smaller insert gradient bore geometry. In this study we compare the performance of a head-insert gradient with a whole body gradient system using highly parallelized RF coils, for high resolution Q-Ball imaging. Bootstrap-based metrics demonstrate higher reproducibility of the Q-Ball orientation distribution functions (ODF) from head gradient HARDI data.

Methods. *Data acquisition*. Acquisitions were conducted on a 3T MRI system (Siemens Healthcare) using the regular body gradient (BG) (40mT/m, slew rate = 200T/m/s) and a head gradient (HG) (AC88, 80mT/m, slew rate = 400T/m/s). A custom-made single channel transmit and 31ch receive coil was used with the HG. A Siemens 32ch coil was used with the regular BG. Data were acquired with the Stejskal-Tanner SE-EPI sequence using the following parameters: TR=3500ms, matrix=138x138, 1.5 mm isotropic, b-value=3000s/mm^2, 60 directions, 6 averages. The TE/echo spacing were respectively 116ms/0.77ms on the BG and 70ms/0.59 ms on the HG.
Data processing. Preprocessing consisted in correcting for subject motion with FLIRT [2], using interspersed b=0 during HARDI acquisition (every 10 measurements). Regular bootstrap was then performed on each of the six repetitions with 500 iterations. For each generated dataset, Q-Ball diffusion ODF (dODF) were estimated [3]. To compare the reproducibility of the estimation in both systems, the Jensen-Shannon divergence was computed between the mean and each estimated dODF, similarly to [4]. Similarly to the root sum of square, the Jensen-Shannon divergence measures the distance between two probability distributions. In this case, the probability distribution was the discrete dODF defined by 1448 samples on the sphere. Also, the first maximum of the dODF was extracted and the 95% confidence interval was computed, as proposed for DTI in [5].

Results. SNR was measured in a white matter region on b=0 (T2) images. SNR was 8.7 for the BG and 12.7 for the HG data. Bootstrap results show better reproducibility of ODF estimate for the HG, with lower uncertainty of maxima orientation (Fig 1). These higher performances allowed us to also demonstrate 1 mm isotropic acquisition (Fig 2).



← Fig 1. Results of bootstrap comparing the whole body gradient (BG) and head gradient (HG) on two different subjects. Slice positioning is matched. The Jensen-Shannon divergence maps describe the difference between each bootstrap ODF. Higher values means higher variability in the estimate of the Q-Ball ODF, reflecting lower reproducibility. The angular confidence maps describe the uncertainty on the orientation of the first maxima of the ODF.



↑ Fig 2. HARDI acquisition at 1x1x1 mm^3 spatial resolution, 80 directions, b-value=3000 s/mm^2. Such a high resolution allows to detect U-fibers and intracortical fibers oriented perpendicular to the white/grey matter surface.

Discussion. Using an insert gradient at 3T we were able to obtain 1mm isotropic HARDI data of sufficient quality to reconstruct the ODF. In addition to the substantial gain in TE yielding better SNR, the HG provides better duty cycle therefore allowing gradients to work at maximum power for a longer period of time. This is particularly suitable for long HARDI protocols using high q-values. Not addressed in this study is also the possibility to obtain very large b-values (>10000) with sufficient SNR and reduced diffusion time, enabling diffusion spectrum imaging studies with smaller voxels than what could generally be achieved (<2mm isotropic) [6]. The pipeline developed in this study allows evaluate the reproducibility of dODF estimates based on regular bootstrap methods. Future work will investigate the performance of the head insert gradients for DSI.

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