# Improved diffusion tractography at the cortical boundary using HARDI acquisitions with high-*b*/low-k in white matter and low-*b*/high-k within and near the cortex

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## TARGET AUDIENCE

Researchers interested in high spatial resolution and/or high *b*-value diffusion imaging, diffusion tractography and structural connectivity analyses using high angular resolution diffusion MRI.

## PURPOSE

Axonal fibers in the brain may take sharp turns at the white/gray boundary before entering the cortex[1], especially in sulcal walls. Diffusion tractography may fail to capture this behavior due to spatial resolution (k-space sampling) limitations. The resulting "gyral bias" is a manifestation of this problem[2], which shows that it is critical to accurately locate the turning point to correctly assign the cortical connection. On the other hand, in deep white matter, high *b*-value is needed to produce the angular contrast and resolve crossing structures[3]. Given SNR constraints, when high *b*-value is used, spatial resolution must be lowered. For full brain structural connectivity analysis, both high-k and high-*b* characteristics are desired, especially in cases of quantitative cortico-cortical connectivity studies. The goal of this work is to improve diffusion tractography near the cortex while retaining the benefits of high *b*-value diffusion imaging in the white matter. This is achieved by combining high spatial resolution diffusion scans at relatively lower *b*-value with high *b*-value diffusion scans at relatively lower spatial resolution.

## METHODS

***Data acquisition and preprocessing:*** Diffusion imaging data were acquired from a healthy adult subject on the Siemens 3T Connectom scanner (up to 300mT/m gradient strength) with a 64-channel head coil. The high-*b*/low-k dataset was acquired with *b*-value of 8000 s/mm$^2$ at 1.9mm isotropic resolution using 128 gradient directions, TE/TR = 52/3000 ms, and FOV=170x120mm. The high-k/low-*b* dataset used a *b*-value of 1500s/ mm$^2$ at 1mm isotropic resolution using 64 gradient directions, TE/TR = 61/6200ms, and FOV=170x120mm. Both acquisitions used FLEET-ACS GRAPPA[4,5] iPAT = 3, MB factor SMS[6,7] = 2, and ZOOPPA[8,9] to suppress unwanted portions of the FOV in the phase encoding direction. The EPI distortions in the two datasets differed due to their differing readout parameters. To correct for the distortions, the scans were repeated with reversed phase-encode blips, yielding a total acquisition time of ~40mins. Susceptibility distortions were corrected using FSL tool TOPUP[10]. The 1.9mm resolution dataset was then upsampled to 1mm voxel size and concatenated with high-k/low-*b* dataset for joint eddy current distortions correction.

***Data analysis:*** First, a standard *q*-ball reconstruction[11] was performed using a maximum spherical harmonic (SH) order $L_{max}$ = 8 for the high-*b*/low-k data and $L_{max}$ = 4 for the high-k/low-*b* data. The regularization parameter λ was set to 0.002 for both datasets. Second, white/gray matter segmentation was obtained from FreeSurfer and registered to the *b*=0 image using the FreeSurfer tool bbregister[12]. The surface between white and gray matter was shifted by 1mm towards the white matter, and a mask of cortical+white/gray boundary region was created. This mask was then used to include in the fused ODF dataset the ODFs reconstructed from the high-k/low-*b* diffusion data. For voxels outside this cortical mask, the high-*b*/low-k diffusion data were used to generate ODF estimates in the fused ODF dataset. Deterministic fiber tracking was performed in DSI Studio.

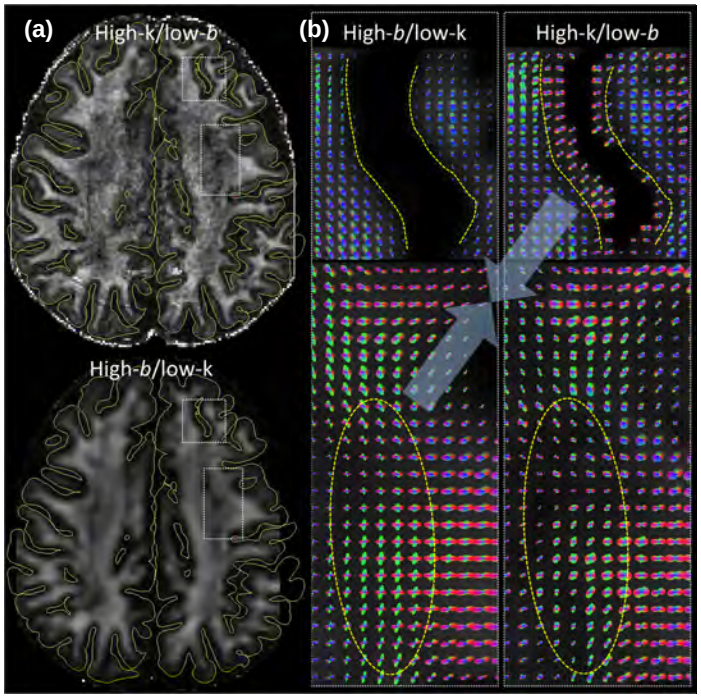


**Figure 1.** FA map and *q*-ball ODFs of the high-k/low-*b* and high-*b*/low-k datasets. (a) FA map with pial surface labeled in yellow. (b) The *q*-ball ODFs in regions circled in (a). The high-k data reveals the diffusion anisotropy in cortical gray matter, and the high-*b* data resolves the crossing structures in the centrum semiovale.

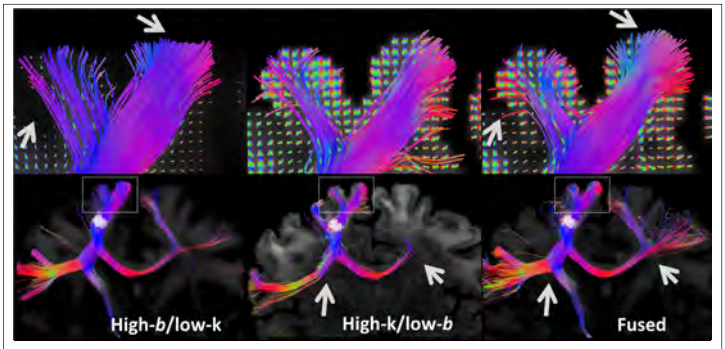


**Figure 2.** Diffusion tractography using the high-*b*/low-k, the high-k/low-*b,* and the fused ODF dataset. The fused dataset resolves crossing fibers in deep white matter and projection fibers (arrows) that are not apparent in the separate datasets alone.

## RESULTS

Figure 1 shows the FA maps and *q*-ball reconstruction results. The high-k/low-*b* data revealed the diffusion anisotropy in cortical gray matter, and high-*b*/low-k data resolved the crossing structures in the centrum semiovale. Figure 2 shows the diffusion tractography results using the high-*b*/low-k, high-k/low-*b* and fused ODF datasets, respectively. The fused dataset combined the benefits of high-*b* diffusion imaging in resolving crossing fiber bundles in deep white matter as well as high-k diffusion imaging in capturing the projection fibers peeling off the major fiber bundles before entering cortical gray matter.

## CONCLUSION AND DISCUSSION

Different brain structures require different imaging parameters to be optimally resolved. Our work demonstrates that it is possible to combine high-*b*/low-k and high-k/low-*b* diffusion datasets for improved tractography not only in deep white matter but also near the cortex, which will ultimately benefit cortico-cortical structural connectivity studies.

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## REFERENCES:

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