Improving cortical tractography using double inversion recovery

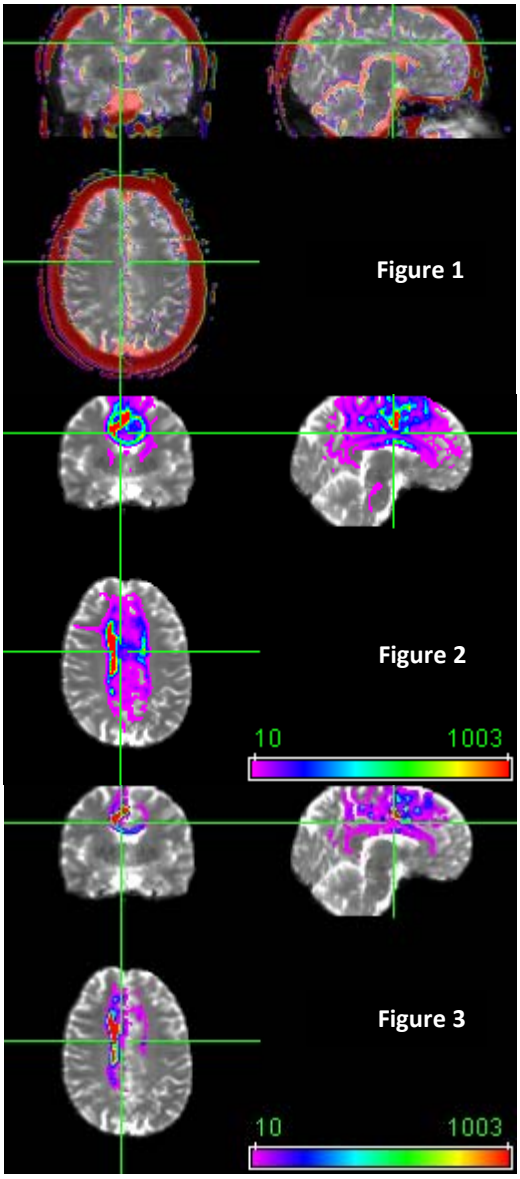
Hamied A Haroon[1], Claude J Bajada[2], Hojjatollah Azadbakht[1], and Sha Zhao[1]

[1]*Centre for Imaging Sciences, The University of Manchester, Manchester, England, United Kingdom,* [2]*School of Psychological Sciences, The University of Manchester, Manchester, England, United Kingdom*

TARGET AUDIENCE Researchers interested in diffusion-weighted imaging and tractography.

INTRODUCTION Water protons in cerebral-spinal fluid (CSF) exhibit isotropic diffusion. If CSF is not correctly masked out in magnetic resonance high angular-resolution diffusion images (HARDI) then tractography can generate spurious and random anatomical connections outside of the brain's parenchyma, via voxels containing CSF. This is a particular problem in the cerebral cortex where inefficient masking out of CSF can allow tracks to "jump" across gyri and sulci erroneously. Usually a high-resolution T_1 volume is acquired along with HARDI data. The T_1 is segmented into different tissue types and the CSF segmentation is co-registered to the diffusion data as a mask. However, the differences in resolution between the T_1 and diffusion images and the associated partial volume effects, lead to inaccuracies in masking out CSF in diffusion space and can even cause parts of the brain parenchyma to be masked out. Here, we present a method based on double inversion recovery (DIR)[1,2] to segment and mask out CSF efficiently and improve cortical tractography.

METHODS *Imaging:* HARDI, Proton-density (PD) and DIR data were acquired in a healthy control (M, 28 years of age), on a 3 T Philips Achieva scanner (Philips Healthcare, Best, Netherlands) using a 32-channel head coil. **HARDI:** PGSE EPI, single shot, TR = 15 s, TE = 59 ms, cardiac gated, halfscan factor = 0.679, 128 × 101 matrix reconstructed to 128 × 128, reconstructed resolution 1.875 × 1.875 mm^2, slice thickness 2.1 mm, 60 contiguous slices, 43 non-collinear diffusion sensitization directions at b = 1200 s/mm^2 (Δ = 32.0 ms, δ = 12.5 ms), 1 at b = 0, SENSE factor = 2.5, total time = 13 mins, corrected for susceptibility and eddy current-induced distortion[3]. **PD:** 3D SE, turbo spin echo factor 75, multishot, TR = 8 s, TE = 9 ms, FA = 90°, 128 × 104 matrix reconstructed to 128 × 128, reconstructed resolution 1.875 × 1.875 × 2.1 mm^3, 60 contiguous slices, SENSE factor = 2.5, total time = 6.7 mins. **DIR-CSF:** 3D IR, turbo spin echo factor 75, multishot, TR = 8 s, TE = 9 ms, TI = 1850 and 2250 ms to annul signal from grey and white matter, 128 × 104 matrix reconstructed to 128 × 128, reconstructed resolution 1.875 × 1.875 × 2.1 mm^3, 60 contiguous slices, SENSE factor = 2.5, total time = 6.7 mins. *CSF Mapping:* PD and DIR-CSF were acquired with the same imaging geometry and were both used to create a normalized probability map of intravoxel CSF, thresholded to produce a binary mask. *Co-Alignment:* The PD volume was co-aligned with the b = 0 images by implementing 3-parameter rigid body registration in FSL's (http://fsl.fmrib.ox.ac.uk/fsl)[8] FLIRT[4,5]. The transformation matrix obtained from this was applied to the DIR-CSF. *Constrained Spherical Deconvolution and Model-Based Residual Bootstrapping:* As described in [6,7] with the exception that the dominant diffusion orientation distribution function was generated with 28 spherical harmonics (l_{max}=6)[8] here. *Probabilistic Tractography:* The fiber orientations estimated over 32 MBR bootstrap iterations in every voxel of the brain formed a probability density function (PDF) for probabilistic tractography using PICo[9,10,11], with 10,000 Monte Carlo streamlines. We used a single principle direction with high uncertainty in a voxel if the number of fiber orientations was greater than 3, on any bootstrap iteration. Probabilistic fiber tracking was seeded from a small region on the medial cerebral cortex in the right hemisphere.



RESULTS Figure 1 shows orthogonal views of the binarised CSF mask from DIR-CSF. Orthogonal views of the b = 0 volume in greyscale overlaid by the binarised CSF mask from DIR-CSF is shown in Figure 1, and overlaid with colour-rendered output of probabilistic tractography are shown in Figures 2 and 3. The colour map is scaled from 0.1% to 10% and greater (of 10,000 streamlines). Figures 1, 2 and 3 are co-aligned. Probabilistic connections generated without a CSF mask is displayed in Figure 2 and with the CSF mask from DIR-CSF (Figure 1) is displayed in Figure 3. It is clear to observe how spurious and random tracks can easily pass through CSF, giving anatomically implausible connections (Figure 1). However, accurately masking out CSF using DIR-CSF ensures that tractography is constrained within the brain and produce anatomically acceptable connections (Figure 2).

DISCUSSION/CONCLUSION The DIR imaging method allows signal to be preserved from just one tissue type in the brain. DIR data are acquired at the same resolution and geometry as HARDI data, and therefore makes DIR an ideal technique to mask out CSF in HARDI data as they are in the same space and the voxels have the same partial volume effects. It is vital to remove CSF-filled voxels from HARDI images before performing tractography in order to reduce false positive connections while enhancing true positive connections. Segmenting tissues (including CSF) on high-resolution T_1 volumes of highly-atrophied brains based on a "healthy" template can be problematic. The DIR method would be best for masking out CSF in such brains for subsequent tractography. DIR is able to preserve signal from CSF most successfully as CSF has a relatively consistent T_1 across the brain, whereas the T_1 values of grey and white matter have greater variation.

REFERENCES [1] Meara SJ, *et al*, Magn Reson Imaging, 26:943, 2008. [2] Meara SJP, *et al*, ISMRM, 1841, 2008. [3] Embleton KV, *et al*, Hum Brain Mapp, 31: 1570, 2010. [4] Jenkinson M, *et al*, Med Image Analysis 5:143, 2001. [5] Jenkinson M, *et al*, 17:825, 2002. [6] Haroon HA, *et al*, ISMRM, 363, 2009. [7] Haroon HA, *et al*, ISMRM, 578, 2010. [8] Tournier J-D, *et al*, NeuroImage, 35: 1459, 2007. [9] Parker GJ & Alexander DC, Lect Notes Comput Sci, 2732: 684, 2003. [10] Parker GJ & Alexander DC, Phil Trans R Soc Series B, 360: 893, 2005. [11] Alexander DC, *et al*, Magn Reson Med, 48:331, 2002.

ACKNOWLEDGEMENTS This work was supported by a BBSRC DTP studentship (BB/J014478/1), The University of Manchester's MRI Facilities, and the National Institute of Health Research/Wellcome Trust Clinical Research Facility, Manchester, UK.