Effects of susceptibility distortions on tractography

J. L. Andersson[1], M. Richter[2], W. Richter[3], S. Skare[1], R. G. Nunes[4], M. D. Robson[5], T. E. Behrens[4]

[1]MRC, Karolinska Institute, Stockholm, Sweden, [2]CSBMB, Princeton University, New Jersey, United States, [3]Department of Chemistry, Princeton University, New Jersey, United States, [4]FMRIB Centre, University of Oxford, United Kingdom, [5]OCMR, Oxford University, United Kingdom

Introduction

There is large current interest in inferring on anatomical connections using diffusion tensor imaging [1] and tractography. At its simplest tractography can be seen as the process of drawing streamlines connecting voxels based on the direction of the most significant eigenvector at each point. Probabilistic techniques allow us to estimate the uncertainty of the relevant model parameters (the direction) and hence of the resulting tract [2]. DTI data are typically obtained using EPI, a technique that suffers from geometric distortions caused by susceptibility induced field changes. It is well known that this can ruin anatomical fidelity, and hence make interpretation more difficult. In addition it could be conceived that non-linear (non-affine) distortions will affect the accuracy of tract tracing (fig. 1). In this paper we examine that hypothesis by performing tractography on data before and after correction for susceptibility distortions [3].

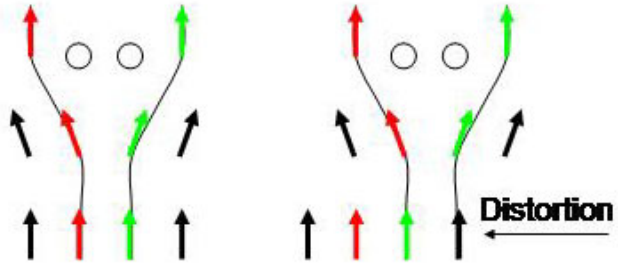
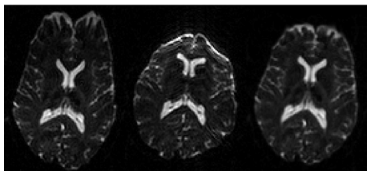


Fig. 1 Schematic description of mis-tracing caused by distortion. In this 4×3 neighbourhood the direction of the largest eigenvector is indicated by an arrow. Voxels with low anisotropy are indicated by a circle. To the left is shown the "correct" tracing in the absence of distortions. To the right is shown what happens if the image is distorted such that the lower row is translated one voxel to the left relative the others. Coloured arrows represent true paths through the data.

Methods

Diffusion data (60 directions) was acquired both on a six year old 3T Varian scanner, and on a state of the art 3T Siemens Allegra scanner, where distortions were considerably smaller. Three acquisitions were performed, twice with positive phase encode blips (kd+) and once with negative (kd-). One kd+ and the kd- data set were used to reconstruct a single set of data with significantly reduced distortions [3]. Probabilistic tractography [2] was performed in the undistorted data set and on a data set consisting of both kd+ acquisitions. Seed points were placed in the medio-dorsal thalamic nucleus, known to project to frontal cortex, and the resulting tracts were compared. The tracts that were estimated from the distorted data were subsequently unwarped into the same space as the corrected images so that any differences should be attributable to differences in the tracing.



k_d+ k_d- Corrected

Fig. 2 Data acquired on the Varian scanner.

Results & Discussion

Unwarping produced images of apparently high anatomic fidelity (fig. 2). The tracts estimated from the distorted and the corrected data would initially follow the same path towards the frontal cortex, but started diverging as they entered frontal areas with field changes originating from the air-cavity of the palate. They would continue to gradually diverge, to finally end in different sulci (fig. 3). Analogous results were obtained with the Siemens scanner, in spite of less sever distortions. Our results show that the process of tract tracing is sensitive to non-linear geometric distortions of the data, even when of the limited magnitude offered by state of the art scanners.

Validation is difficult because of lack of ground truth. We would however suggest the following chain of indices in support of the results based on our correction method. 1. There is a simple model (fig. 1) to suggest why distortions might change the outcome of tract tracing. 2. Results are different between original and corrected data. 3. It is quite clear from visual inspection that images are more anatomically faithful after correction. Furthermore, the correction changed the results in such a way that the yellow tract in fig. 3 is consistent with the medio-dorsal→prefrontal tract previously found on a lower field (distortion) scanner [4].

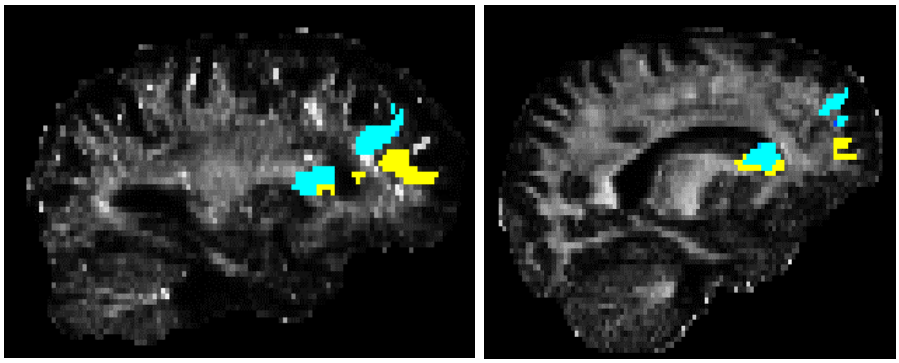


Fig. 3 Sagittal view of tracts running from medio-dorsal thalamus to frontal cortex. The tract estimated from the original data (blue) finish at a different sulcus from that estimated from the corrected data (yellow). In the present plane we see both the point of divergence (left) and the point of entry into cortex. These data on the left were collected on the Varian scanner and those on the right on the Siemens scanner.

References

[1] Basser P & Pierpaoli P. 1996, *JMR* 111:209-219.

[2] Behrens T et al. 2003, *MRM* 50:1077-1088.

[3] Andersson J et al. 2003, *NeuroImage* 20:870-888.

[4] Behrens T et al. 2003, *Nat Neurosc* 6(7):750-757