Acquiring optimal DWI data for tractography on post mortem brain tissue

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Introduction

Studies upon post mortem brains, compared to those in vivo, benefit from the option of using high-field (experimental) MR scanners, longer scanning times and stronger diffusion weighting gradients, thereby improving both the image resolution and SNR. Moreover, many of the degrading effects observed in vivo such as physiological noise are absent at post mortem. However, when acquiring DWI datasets on post-mortem brains the b-value must be adjusted to compensate for a decreased apparent diffusion coefficient which is primarily caused by two factors: 1; a lowered environmental temperature, determined by the temperature inside the core of the magnet, and 2; an unknown factor dependent upon the fixation process. To this end, we have exploited some of the many advantages of post-mortem scanning. In order to investigate and compare the ability of appropriate b-values to resolve both single and heterogeneous fibre compositions we have compared different DWI datasets from one continuous scanning session using a wide range of b-values. This is a critical component for validating DWI based tractography, as recently presented by Dyrby et al (2007).

Method

Diffusion weighted imaging was obtained in a perfusion fixated pig brain on an experimental 4.7T Varian Inova scanner. In order to reduce any short term instabilities (due to handling of the brain tissue and temperature differences) the brain was placed in the scanner for 15 hours before the acquisition of the DWI dataset. Seven DWI datasets with increasing b-values were obtained: 1018, 2475, 3069, 4009, 5911, 8181 and 15750 s/mm^2. To exclude spatial differences between the DWI datasets all data was acquired within the same scanning session. Additionally, to reduce geometric image distortions and to minimize susceptibility artefacts (e.g. due to air bubbles), a conventional diffusion weighted spin echo sequence (dwSE) was used: TE: 67.8 ms; TR: 2500 ms; FOV: 65x32 mm; matrix: 128x64; 5 slices; voxel size: 0.51x0.51x0.5 mm^3. Diffusion parameters were: DELTA: 33.5 ms; delta: 27 ms, and seven different gradient strengths: 29, 44, 49, 56, 68, 80 and 111 mT/m. Each DWI dataset consisted of 3 non-dw and 61 dw (non-collinear directions) image volumes. A NEX=4 resulted in a SNR of 21.

Two reconstruction methods were used for voxel-wise modelling of the underlying true fibre compositions. *Method I*: Spherical harmonics (SH) of order 0th, 2nd and 4th were fitted to each voxel and a voxel-wise F-test for each SH was calculated (Alexander et al, 2002). For classification, user defined thresholds of the F-tests were used to categorize the voxels into one of the three orders of SH, representing isotropic, anisotropic or non-Gaussian diffusion profiles. The latter class includes mixed compositions such as crossing fibres. The F-test thresholds selected were: 1E-13 for segmenting iso- and anisotropic profiles and 1E-8 to segment anisotropic and non-Gaussian profiles. Since all DWI datasets had similar SNR the same thresholds were used. *Method II:* Persistent angular structure (PASMRI) is a q-space method that via a Fourier transformation searches for the best spherical fit to reflect the angular displacement density of water molecules. The peaks of the spherical function provide the estimated fibre orientations of a single or more fibres crossing within a voxel. Both methods are available in the Camino diffusion toolkit (Cook et al. 2006).

Results

Clusters containing non-Gaussian voxels become apparent for b-values > 2475 s/mm^2 (Fig. 1D) further increasing with b. For b-values > 8181 s/mm^2 the size of cluster was found to be more sensitive to the selected F-threshold than at lower b-values. Additionally, clusters of isotropic voxels start to appear in the brain tissue (Fig. 1G). Reconstruction using PASMRI was found to be robust in detecting single as well as crossing fibres across the whole range of b-values. However, for low b-values (1018s/mm^2) the contrast between fibre directions was decreased as the PAS direction distributions were broadened. In addition, a reduced spatial agreement between neighbouring voxels was observed compared to the higher b-values (Fig. 1 I, J).

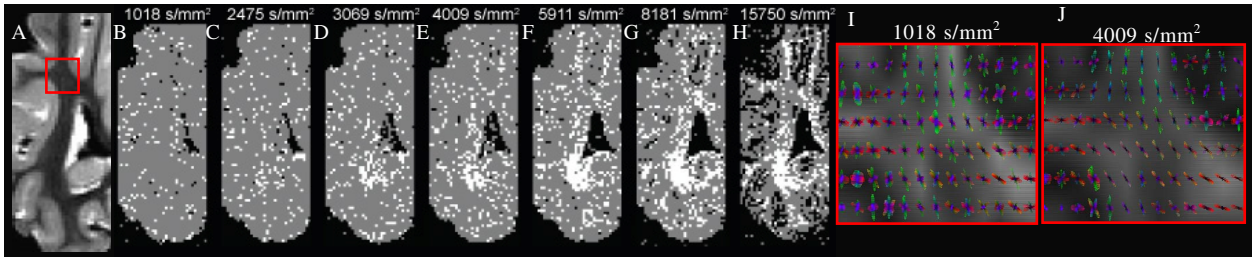

Fig. 1 The ability to robustly detect heterogeneous fibre compositions in the pig brain was investigated using two reconstruction methods applied to a DWI dataset with increasing b-values. (A) Non-dw image of the half pig brain used. (B-H) Voxels classified as containing isotropic (black), anisotropic (grey) or non-Gaussian (white) fibre profiles. (I-J) Colour coded visualisation of PASMRI reconstructed fibre directions overlaid onto the FA map obtained at a b-value of (I) 1018 s/mm^2 and (J) 4009 s/mm^2.

Conclusion

We demonstrate that a main prerequisite for robustly detecting fibre compositions from a DWI data set on post mortem tissue is the proper selection of b-values from within a narrow range. We demonstrate a lower bound of b >2475 s/mm^2 and a upper bound of b < 8181 s/mm^2, depending upon how sensitive the particular reconstruction method is to the noise floor. In addition, we demonstrate the enormous potential in using post mortem brain tissue in a controlled neuronal environment. The model allows for further improvements of modelling methods used in tractography as close as possible to the 'true' in vivo neuronal environment.

References

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