Comparison of methods for high angular resolution diffusion imaging

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Synopsis

Several methods exist for characterizing the orientational dependence of diffusion in tissues. Although these differ widely in their requirements for data acquisition and underlying assumptions, little work has been done to compare the available methods and identify their relative strengths and weaknesses. This work makes a direct comparison of five different approaches using *in vivo* human data.

Introduction

It is well known that partial volume averaging of tissues with distinct diffusion properties leads to errors in diffusion tensor imaging (1). A number of techniques have been developed to accurately model diffusion in the general case of multiple or divergent fibers occupying a single voxel (2-6). Diffusion spectrum imaging (DSI) measures the diffusion weighted signal at many combinations of diffusion direction and weighting, and yields an orientation distribution function (ODF) that describes the angular variation in spin displacements (2). High angular resolution diffusion (HARD) imaging estimates the apparent diffusion coefficient at many orientations (one level of diffusion weighting) and allows a decomposition into a sum of spherical harmonics (3). If it is assumed that diffusion within every fiber is axially symmetric, then the angular distribution of fibers can be estimated using a similar spherical harmonic decompositon (4). An abbreviated version of the DSI experiment requires data sampled at many angles but one level of diffusion weighting, and is known as q-ball imaging (5). Each of these methods was implemented in order to make side-by-side comparisons of the results.

Methods

A DSI experiment was performed (4500 s/mm2 maximum tr(b) value, 3 R-R repetition time, 83 ms echo time, 20 cm field of view, 10 mm slice thickness, 64x64 image matrix, 26 minute total acquisition time) using a pulsed gradient, dual spin echo pulse sequence on a 3 Tesla GE scanner. Images were acquired at 502 points on a uniform grid in a hemispherical volume of **q**-space, along with 9 non-diffusion weighted images. These data were used to calculate the orientation distribution function and to estimate by interpolation the signal that would be measured in a HARD experiment (fixed tr(b) = 3000 s/mm2 with 92 measurement directions given by the second order icosahedral tessellation of a sphere). The interpolated data were used to construct the q-ball ODF, the angular distribution of fibers assuming axially symmetric diffusion in all fibers, the ADC calculated at each orientation, and the ADC estimated from the least-squares fit to a single tensor model. Using the same data set for all analysis methods reduces the duration of the study and mitigates some potential sources of variability (e.g., subject motion). To highlight the orientational information in the ODF, only the anisotropic part of the ODF (i.e., the value of the function minus its minimum value) was plotted.

Results

Results for two representative voxels in the brain of a volunteer are shown in the figure. The information provided by the five methods is similar in the case of parallel fibers in the corpus callosum (top row of the figure): all methods show highly anisotropic diffusion parallel to the axons in this structure. The results are more complex in an area of crossing fibers (bottom row of the figure). The two methods for estimating the ODF (i.e., DSI and the q-ball technique) yield very similar results (compare **b** with **c**, and **h** with **i**). Because the q-ball acquisition requires only 20% of the time necessary for the DSI experiment, the q-ball technique is preferable. At the level of diffusion weighting used here, only the axisymmetric fiber angular distribution function resolves crossing fibers (**j**), although further analysis of the ODF (**h** and **i**) and HARD ADC (**k**) may also reveal discrete fiber structures. The single tensor model cannot describe diffusion in complex fiber structures and only reveals decreased net anisoptropy (**l**).

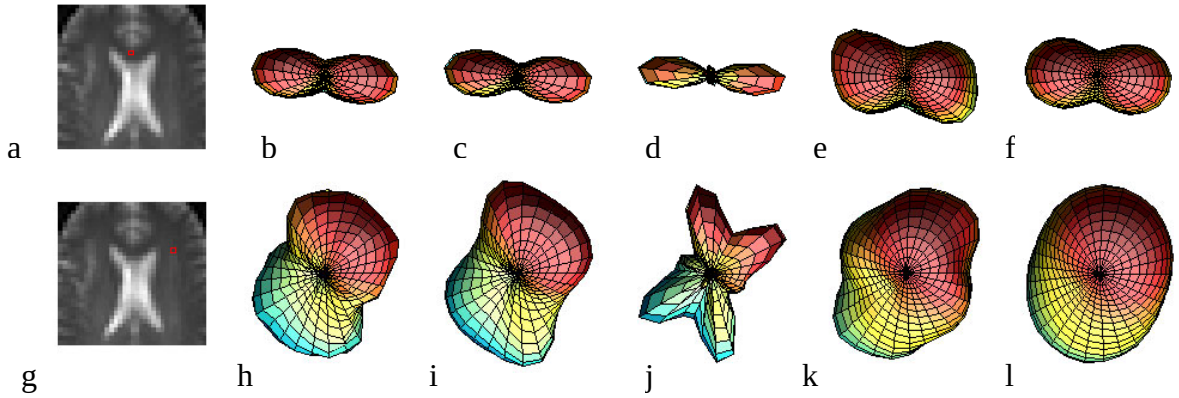

Figure 1. Examples of measurements of diffusion anisotropy in the brain. The top row of plots (**b**-**f**) depict diffusion in a voxel in the genu of the corpus callosum (shown in **a**). The bottom row of plots (**h**-**l**) show diffusion in a lateral voxel in the frontal white matter (shown in **g**). Columns show specific representations of diffusion for the two voxels: the anisotropic part of the DSI orientation distribution function (**b** and **h**), the anisotropic part of the q-ball orientation distribution function (**c** and **i**), the axially symmetric fiber angular distribution (**d** and **j**), the high angular resolution diffusion coefficient (**e** and **k**), and the conventional tensor model of diffusion (**f** and **l**).

References

1. A.L. Alexander et al., Magn. Reson. Med. 45:770-780 (2001).
2. V.J. Wedeen et al., Proc. Intl. Soc. Mag. Reson. Med. 8, 82 (2000).
3. L.R. Frank, Magn. Reson. Med. 45:935-939 (2001).
4. A.W. Anderson and Z. Ding, Proc. Intl. Soc. Mag. Reson. Med. 10, 440 (2002).
5. D.S. Tuch et al., Proc. Intl. Soc. Mag. Reson. Med. 11, 63 (2003).
6. R. Blyth et al., Proc. Intl. Soc. Mag. Reson. Med. 11, 240 (2003).

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