Impact of Resolution on Tissue-Specific DTI Parameters at 3T: Roles of Partial Volume, SNR and Tissue Structure

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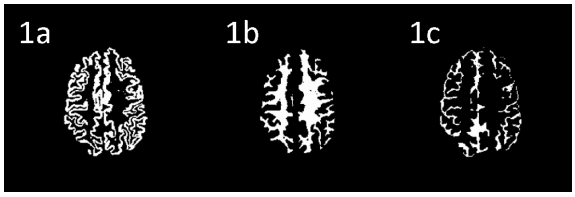
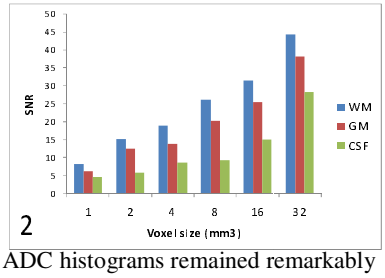
Introduction: diffusion tensor imaging (DTI) is the MRI modality with the most intimate relation to the microscopic structure of tissue. DTI parameters such as apparent diffusion coefficient (ADC), fractional anisotropy (FA), axial and radial diffusivities reflect, albeit not in a fully characterized fashion, properties such as axonal and cellular dimension and densities as well as changes in myelination. With the wider availability of high field MRI, the spatial resolution in which DTI data are collected, even if far below the cellular/axonal size, reaches a point where (a) it is possible to consider acquiring DTI data from cortical gray matter and (b) the actual values of DTI parameters, whether in brain white matter or gray matter, differ significantly from those measured at lower resolutions. Here we offer a systematic view of the two most ubiquitous DTI parameters, i.e. ADC and FA, obtained from a set of experiments performed in a wide range of spatial resolutions (1mm^3-32mm^3) at 3T. We analyze the tissue-specific characteristics of ADC and FA histograms in cortical gray matter, white matter and CSF, following a masking of the DTI data with carefully segmented tissue-specific masks derived from high-resolution T_1-weighted images. By following the behavior of histograms of the three eigenvalues of the diffusion tensor in the three tissue components, we offer a possible explanation of the dependence of ADC and FA in brain gray and white matter on resolution, based on an interplay among signal-to-noise ratio (SNR), partial volume effects of cerebrospinal fluid (CSF), and the impact of macroscopic structure.

Matrix size	Slice (mm)	Voxel (mm^3)	n. avg.
256x256	1	1	8
256x256	2	2	5
256x256	4	4	3
128x128	2	8	3
128x128	4	16	3
128x128	8	32	1

Materials and Methods: scans were performed on a male human subject on a 3T Philips Intera scanner, using the 6-channel SENSE synergy head coil. A slab of 3.2cm thickness and a FOV of 256x256 mm^2 in a well-shimmed dorsal part of the brain was selected for the scans (B_0 maps predicting shifts of less than 0.2 pixel in the highest resolution). Table 1 specifies the data matrix/slice thickness combinations for the set of 6 different resolutions. Data was zero-filled once in each in-plane direction and the resolutions stated reflect this fact. Different number of averages was used to allow reasonable SNR. DTI parameters: single-shot SE-EPI, TR/TE=4000ms/90ms, b=1000, SENSE factor=2, 15 gradient directions. High-resolution 3D-T_1W-FFE (1mm iso-voxel, TR/TE=7.3ms/3.4ms). DTI sets were averaged and co-registered post-scan, and each resulting DTI set was co-registered with the skull-stripped 3D-T_1W-FFE using standard affine transformation. Diffusion tensor calculation was performed using a home written C++ program. Segmentation of white matter/gray matter/CSF was performed and binary masks were generated from the segmented data (example in figure 1 is given for gray matter (a), white matter (b) and CSF (c) masks). DTI data were re-sampled to 1mm^3 resolution. Histograms of masked DTI parameters sets ($\lambda_{1,2,3}$, FA, ADC) were generated and analyzed using MATLAB.





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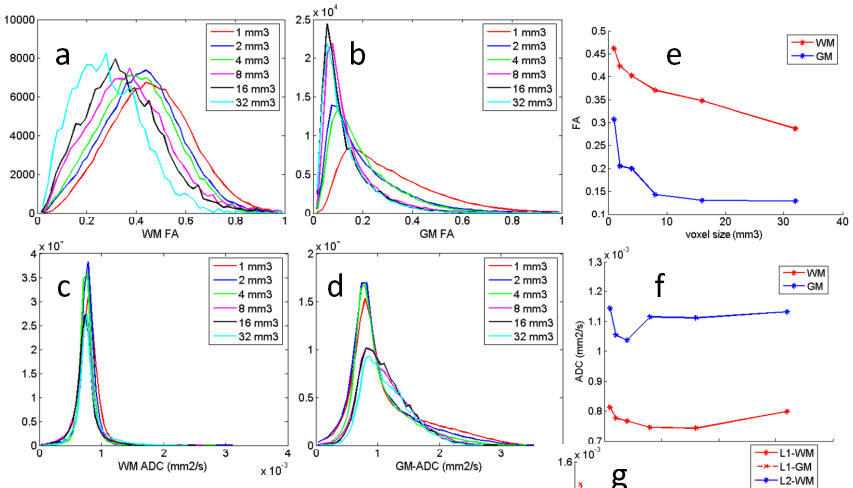
Results and discussion: SNR estimates based on *pre-averaged* DTI images are given in figure 2. A set of FA histograms for white matter (WM) (3a) and gray matter (GM) (3b) at different voxel sizes shows a constant decrease in average FA with increased voxel size in WM, but a more complex behavior in GM. WM ADC histograms remained remarkably similar for all resolutions, which was not the case for GM. (3c and 3d, respectively). Average values of FA (3e) and ADC (3f) for both types of tissue as a function of resolution are given, as well as the tensor eigenvalues (3g).



The monotonous increase in λ_1 and the monotonous decrease in λ_3 in white matter may indicate that given the sufficient SNR (also attested by the fact that rician noise did not cause under-evaluation of λ_1 at the highest resolution[1], and by the relative stability of the ADC), most of the resolution-dependent changes in FA in white matter are indeed caused by macroscopic effects (e.g. intravoxel curvature of WM tracts), which are expected to degrade FA at low resolution. The picture is entirely different for gray matter, where partial volume with CSF and WM on the one hand and lower SNR due to higher ADC pull in different directions. Connectivity in GM is less macroscopically organized and thus the decrease in all three eigenvalues with increase resolution can be explained by the gradual exclusion of CSF as a factor that affects the overall diffusivity, as seen in the lower voxel sizes in 3f. It is suspected that the jump in GM eigenvalues at the highest resolution is a result of reaching the limits of GM SNR as seen in fig.2. Data on CSF was also collected and not shown for lack of space. In these data the complementary effects of partial volume with GM can be vividly seen. In ***conclusion***, the impact of resolution on GM and WM DTI parameters is explored, which leads to potential understanding of the relationship between tissue-specific structural characteristics and DTI parameters.

Selected references: 1. Jones, D. K. and P. J. Basser, Magn Reson Med **52**(5): 979-93; 2. N. Papanikolaou and N. Gourtsoyiannis, Eur Radiol (2006) 16: 187-192; 3. A.W. Anderson, Magn Reson Med 46:1174-1188 (2001);