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NON-PARAMETRIC ANISOTROPY BASED ON GENERALIZED Q-SAMPLING ODF

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Introduction: Local voxelwise measures such as fractional anisotropy (FA), apparent diffusivity coefficient (ADC), or mean diffusivity (MD) [1,2] have been extensively adopted in clinical and applied research practice based on diffusion weighted MR imaging (dMRI). This underlines the need for valid and reliable measures which can indicate the degree of local organisation of white matter in the brain. The measures listed above are based on the parametric simple diffusion tensor (SDT) model [1] which works well when there is a single dominant fibre direction but is also known not to give valid information if the local organisation is more complex [2,3]. We show how model-free, alternatives can yield non-parametric anisotropy and directionality measures (NPA). These are constructed from the spin orientation distribution function (sODF) of Yeh et al. [3] using their generalised q-space sampling imaging (GQI) reconstruction method. We apply exact analytical results which show the form of the sODF when the single tensor model is correct, and further indicate how the tensor's parameters may be estimated from this model-free approach. We compare the performance of these parametric and non-parametric measures for simulated data.

Methods: Simulations were computed for a 102-point grid sampling scheme, with a maximum b-value of 4000s/mm^2. The simulated fibre was aligned with the gradient frame of reference, and the diagonal elements of the diffusion tensor, D, where chosen to match typical values for white matter: l1=1.4 x 10 ^-3 mm^2/s, and l2=l3=0.35 x 10^-3 mm^2/s. Variable fibre orientation was realised by spatially rotating the simulated fibres at discrete orientations. 100 orientations were used, which spanned uniformly the space of (theta, phi). In addition to the SDT a two compartment model with an isotropic component was added with volume fraction 0.5 and diffusivity 0.7 x 10^-3. For each acquisition scheme and fibre type, the “ideal” (noise-free) diffusion weighted signals were calculated according to the SDT model [1], assuming a constant ideal value of the baseline signal S0 = 100. Complex Gaussian noise was then superimposed upon the ideal signals to provide the complex noise-contaminated signals and their magnitude was then obtained. This results in noisy values with a Rician distribution, which can be scaled in order to set the signal to noise ratio to any desired level. In this study the SNRs were 20, 40, 60, 80, and 100.

The sODF and SDT were fitted using dipy (diffusion imaging in python [4]). The sODF was calculated for a tesselated spherical icosahedron with 362 vertices. Two values (1.2 and 3.5) were used for L_Delta, the diffusion sampling length. Non-parametric FA (NPA) was calculated from the sODF by (1) locating the vertex V1 with maximum sODF value max_1; (2) with V1 as pole, locating the vertex V2 on the corresponding equatorial band of width ±5 degrees with maximum sODF value max_2; (3) locating a vertex V3 in the equatorial band at approximately 90 degrees away from V2, denoting the sODF value of max3 at V3. With npd_1 = max_1^2, npd_2 = max_2^2, and npd_3 = max_3^2, non-parametric anisotropy (NPA) was calculated by applying the classical FA [5] formula to the 3 values (npd1, npd2, npd3). The rationale for the squared sODF values is based on Tuch's [2] formula for ODF in the SDT case which implies that the ODF in the 3 principal axis directions of the tensor is proportional to the square root of the corresponding eigenvalue of the tensor. We have further derived an exact formula max_j ∝ sqrt(l_j)*[CDF(c*L_Delta/sqrt(l_j)) - .5] where c a constant that depends on the acquisition parameters though we do not present results relating to this here.

Results: The average NPA and FA are presented below for 200 simulations for each noise level, and single fibres with or without an isotropic component and with different diffusion sampling length. We can see that NPA gives very similar results with FA and as expected it is modulated by the degree of smoothing controlled by the value of the diffusion sampling length.

Discussion and Conclusion: We plan to extend this approach with voxels containing multiple peaks where FA would be unable to give an informative result and also extend it to other types of ODFs. In summary, we have shown that an informative new scalar anisotropy function (NPA) can be calculated without fitting just from the spin ODF which promises to be a model-free proxy for FA. NPA differs from GFA [6] in that it uses just 3 values of the sODF with a geometric relationship instead of the entire ODF.

References:

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