A GEOMETRIC ANALYSIS OF DIFFUSION TENSOR MEASUREMENTS OF THE HUMAN BRAIN

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Introduction

The anisotropy (A_d) of the diffusion tensor (DT) is a scalar measure of the deviation from the spherically isotropic case [1]. Numerous measures of DT A_d have been proposed [1-5]. These measures are based upon the eignenvalues, λ_1, λ_2 and λ_3, of the DT. The relationships between DT shape and A_d are not well-defined.

The DT shape may be represented by the sum of three basis shapes [4] -- linear, planar and spherical:

$$CL = \frac{\lambda_1 - \lambda_2}{3\langle\lambda\rangle},\ CP = \frac{2(\lambda_2 - \lambda_3)}{3\langle\lambda\rangle},\ \text{and}\ CS = \frac{\lambda_3}{3\langle\lambda\rangle}.$$

The normalization by the average eigenvalue causes each measure to range between 0 and 1. The sum of the three shape measures is 1. Since their sum is a constant value, the shape can be represented on a 3-phase (3P) plot using barycentric coordinates [6,7] with the shape measures at the three corners of the plot (Fig 1). The effective distances between each of the three shape cases are equivalent. The position for a DT shape is found by triangulating two shape measures. The left and right sides of the plot correspond to cylindrically symmetric diffusion tensors. The 3P was used to visualize and compare the shape dependence of 4 previously reported DT A_d measures -- the anisotropy index [4], *CA*, the relative anisotropy [1,2,3], *RA*, the fractional anisotropy [1,2], *FA*, and the volume ratio [1,2], *VR*. To compare *VR* directly with the others, a measure called the volume fraction is defined, *VF* = 1-*VR*. *CA*, *RA*, *FA*, and *VF* are normalized to range between 0 = isotropic and 1 = most anisotropic. Each A_d measure was plotted as an intensity on the 3P plot as a function of position (Fig 2).

Materials and Methods

DT-MRI was performed on 4 volunteers with informed consent. Imaging parameters were TR/TE = 6000/90 msec, FOV = 240 x 240 mm^2, 128x128 image matrix. 10 adjacent 4mm coronal slices were prescribed. The diffusion-weighting was b = 1002 sec/mm^2. The pulse sequence was configured to obtain six sets of non-colinear diffusion-encoded images plus a reference (b=0) [8]. *CL*, *CP*, *CS*, *CA*, *RA*, *FA*, and *VF*, were measured for voxels corresponding to corpus callosum (CC), internal capsule (IC), arcuate fasciculus (AF), subcortical white mater (SCW), gray matter (GM), lentiform nucleus (LEN) and thalamus (TH).

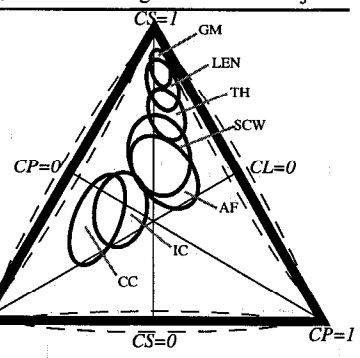

Fig 1. 3P DT shape diagram. Isocontours of one standard deviation for estimates of bivariate normal distributions for each tissue type are plotted. The distributions are highly overlapping in three groups of tissues: (1) CC and IC, (2) AF and SCW, and (3) GM, LEN and TH.

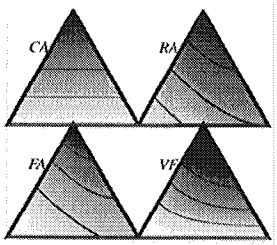

Fig 2. Parametric intensity maps of four anisotropy measures. The 0.25, 0.5 and 0.75 anisotropy levels are indicated as isocontours for each measure. The brightest voxels correspond to A_d = 1 while the darkest voxels correspond to isotropic diffusion.

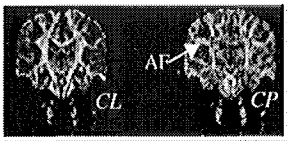

Fig 3. Maps of DT shape measures Commissural (CC) and projection (IC) WM are emphasized on the *CL* map. Association WM appear to have a significant *CP* component.

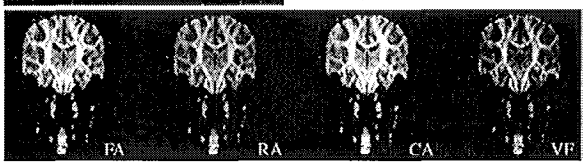

Fig 4. Parametric maps of DT A_d show significantly different gray matter versus white matter detail. All the parametric maps (0 to 1) are scaled to the same relative gray scale range (0 to 255).

Results & Discussion

Maps of *CL* and *CP* (Fig 3) illustrate that the commissural and projection white matter (WM) tracts are highly linear, whereas, many of the association WM fibers have significant *CP* contributions. The causes of planar diffusion in the brain may include membranes arranged in sheets; however, a more likely origin is the crossing and twisting of WM fibers and overlap of GM tissues within a signal voxel. Fig 4 illustrates that WM features appear different for each of the A_d measures. These differences arise from the relative contributions from the *CL* and *CP* shape components of the DT (Fig 3) which can be inferred from the maps in Fig. 2. In all of the images, regions of GM appear dark.

The mean position and covariance matrices in 3P space for each tissue class from all 4 subjects are estimated and plotted in Fig 1. GM measurements are clustered near the top indicating isotropic diffusion. Deep nuclei (TH and LEN) contain some axon connections and are slightly more anisotropic and the most planar. The next most anisotropic tissue groups are the association WM fibers -- AF and SCW. The CC and IC are the most highly anisotropic tissues with high *CL*. Fig 1 demonstrates that it may be possible to segment brain tissues based upon their tensor shape parameters.

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