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## Diffusion Tensor Imaging of Brain White Matter Anisotropy

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### Introduction

Different approaches have been used to measure brain tissue anisotropy. The most widely used is the ratio of ADCs measured with diffusion gradients presumed to be parallel and perpendicular to the fiber directions [ADC(90)/(0), (1)]. Recently, another scalar index of anisotropy was proposed using ADCs measured with diffusion gradients applied in three orthogonal directions [Standard Deviation index (SD), (2)]. On theoretical grounds, these two indices are affected by the orientation of the fiber-tracts with respect to the directions in which diffusion gradients are applied. Anisotropy ratios derived from diffusion tensor imaging (DTI) overcome this deficiency (3). Ratios of the principal diffusivities (eigenvalues) of  $\underline{D}^{eff}$ ,  $\lambda_1$ ,  $\lambda_2$ , and  $\lambda_3$ , are invariant to rotations of the tissue within the NMR magnet (4).

Our purpose was to compare the accuracy and utility of these measures in assessing diffusion anisotropy. We also evaluated the use of the diffusion tensor scalar quantities and functions of them as features with which to characterize various tissue types based on their water diffusivity properties.

### Materials and Methods

We studied three 2-3 year old cynomolgus monkeys. Each animal was imaged three times with a quadrature head coil on a 2.0-T CSI-Omega imaging system. Body temperature was kept at  $37 \pm 0.3$  °C and cardiac gating using ECG recordings was performed.  $\underline{D}^{eff}$  was optimally estimated in each voxel (1,3) and  $\lambda_1$ ,  $\lambda_2$ , and  $\lambda_3$ , were calculated from sets of 14 multislice diffusion-weighted coronal images (2s TR, 70ms TE, 40ms diffusion time, 128x256 matrix). In addition to ADC(90)/(0) and SD we calculated two anisotropy indices based on the eigenvalues of  $\underline{D}^{eff}$ : the ratio of the largest and the smallest eigenvalue in each voxel ( $\lambda_1/\lambda_3$ ) and another index (Vol-ratio),

$$Vol-ratio = 27 \frac{\lambda_1 \lambda_2 \lambda_3}{(\lambda_1 + \lambda_2 + \lambda_3)^3} = 27 \frac{Det(\underline{D}^{eff})}{Tr(\underline{D}^{eff})^3}$$

Geometrically, this formula represents the volume of the diffusion ellipsoid divided by the volume of a sphere whose diameter is  $Tr(\underline{D}^{eff})/3$ . The possible values of Vol-ratio range between 0 and 1, where 0 indicates the highest anisotropy and 1 represents complete isotropy.

### Results and Discussion

Table 1 shows the four diffusion anisotropy indices (mean  $\pm$ sd, n=9) calculated for four different ROIs. In the coronal slice, the corpus callosum (CC) is oriented horizontally, the posterior internal capsule (PIC) is oriented vertically, and the ventral internal capsule (VIC) is oriented obliquely with respect to the x- and y-directions. The parietal cortex is representative of structures that are isotropic. The VIC data clearly show that both ADC(90)/(0) and SD fail to reveal the anisotropic white matter tracts running at an oblique angle to the applied gradients. This is

also evident by comparing the SD and Vol-ratio anisotropy images displayed in Fig 1a and b where oblique white matter tracts are nearly invisible in the SD image. CC and PIC are predicted to be anisotropic by all methods but the degree of anisotropy is different in each case. Table 1 shows that using the eigenvalue ratio,  $\lambda_1/\lambda_3$ , the water diffusivity in the direction parallel to the fibers is about 10 times higher than in the orthogonal direction--and about 3 times higher than what is usually quoted, and what we found in the same ROIs using ADC(90)/(0). Despite the fact that  $\lambda_1/\lambda_3$  is noisier than the other indices, this discrepancy appears to be significant and it is supported by the values of the Vol-ratio index.

Table 1

	$\lambda_1/\lambda_3$	ADC(90)/(0)	Vol-ratio	SD
Corpus Callosum	13.3 $\pm$ 4.1	3.75 $\pm$ 0.46	0.19 $\pm$ 0.03	0.28 $\pm$ 0.04
Posterior Int. Capsule	11.6 $\pm$ 3.2	2.78 $\pm$ 0.36	0.23 $\pm$ 0.04	0.35 $\pm$ 0.06
Ventral Int. Capsule	8.9 $\pm$ 2.4	1.16 $\pm$ 0.06	0.26 $\pm$ 0.07	0.93 $\pm$ 0.03
Parietal Cortex	1.7 $\pm$ 0.5	0.99 $\pm$ 0.04	0.92 $\pm$ 0.06	0.96 $\pm$ 0.03

Figure 1. Anisotropy index images:



A) Volume ratio

B) SD

### Concluding Remarks

1) Diffusion tensor imaging is more accurate in characterizing diffusion anisotropy in vivo than other methods in which the measurement is affected by the orientation of the fiber-tracts with respect to the laboratory frame.

2) Diffusion anisotropy in white matter is much larger than previously reported.

### References

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