The Observed Heterogeneity of DTI Scalar Metrics in High and Low FA Regions of Brain Abscess

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Introduction: Since the molecular diffusion is anisotropic in the white matter fiber tracts, the Fractional anisotropy (FA) computed in the diffusion tensor magnetic resonance imaging (DT-MRI) is indicative of the axonal directionality in the brain[1]. In contrast, low FA is associated with the grey matter or the cerebrospinal fluid in the brain. Brain abscess can be characterized by low mean diffusivity (MD) as compared to normal brain parenchyma on diffusion-weighted imaging (DWI). In vivo proton magnetic resonance spectroscopy and diffusion weighted imaging alone or in combination have been used in the differentiation of abscess from the non-abscess lesions[2]. Recently, we have reported a remarkably high FA in the cavity of brain abscess patients with low MD using DT-MRI[3]. In this study we analyze the DT-MRI data of patients with brain abscess to understand the role of eigenvalues in explaining this heterogeneity in the abscess cavity and orientation of pus cells associated with high FA.

Methods: Seven patients with brain abscess including 4 males and 3 females aged from 4-55 years formed the study group. The final diagnosis was based on the aspiration and culture of the pus. Equal number of normal healthy volunteers including 6 males and 1 female were also imaged for comparison in this study. DT-MRI was performed on 1.5 Tesla MR Scanner (Echospeed plus, GE Medical System, Milwaukee, WI) using single-shot echo planar dual spin-echo sequence with ramp sampling. The diffusion weighting b-factor was set to 1000s/mm2, TR~8sec, TE~100ms. A total of 21 axial sections were acquired with a slice thickness of 3mm, no gap, FOV= 240 mm x 240 mm and an image matrix of 256x256(following zero filling). The diffusion tensor encoding used was the balanced, rotationally invariant icosahedral scheme with 21 uniform directions over the unit hemisphere[4, 5].

Processing and Quantification: The removal of scalp to isolate the brain in the collected raw images was done, in all cases, by an automated stripping procedure[6]. The extraction of patient abscess lesion could be easily done using a freehand interactive polygon method on diffusion-weighted images. This extracted lesion was further divided into two sub-regions: with FA<0.2 and FA≥ 0.2. An automated segmentation[5] was needed for the extraction of the more complex white matter on normal volunteers, also subdivided into regions with FA<0.2 and FA≥ 0.2.

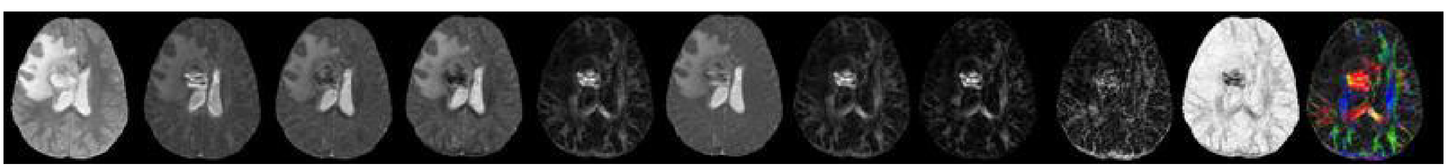
Subsequent DTI processing did not require any filtering or registration, as justified by the absence of unprocessed voxels. The 21×6 over-determined system was subjected to Moore-Penrose solution for the diffusion tensor at each voxel. The eigenvalues/vectors of the diffusion tensor matrices in the ROI were calculated. The orthogonality of the computed eigenvectors and the correctness of the eigenvalues were checked using random sampling at a number of voxels. The correctness observed was up to an order of 10^{-17}, indicating that no iterative refinement of the computed eigenvalues/vectors was needed. The tensor field data was than used to compute the DTI metrics such as MD, FA, RA, linear (CL), planar (CP) and spherical (CS) measures for each ROI voxel. (The present computations were done by inhouse routines developed at the advanced digital imaging solutions laboratory (ADISL) at IIT Kanpur[6]).

Results: The variables quantified in the abscess cavity as well in the normal white matter are summarized in Table 1. In FA<0.2 region of the abscess cavity λ_1, λ_2, λ_3, RA, FA, CL, CP were significantly lower, while CS was significantly higher as compared to normal white matter; while in FA≥ 0.2 region, λ_1, λ_2, λ_3, MD and CS were significantly lower but RA, FA, CL, CP were significantly higher. Surprisingly, the heterogeneity of the DTI metrics, indicated by high SD in the abscess parameters is much more conspicuous. Images of b_0(b=0), λ_1, λ_2, λ_3, RA,MD,FA,CL,CP,CS and color map of eigen vectors weighted with FA are respectively shown below the table.

Table 1: Summary of various invariants in abscess cavity as well as the normal subjects*

DTI Metrics	**FA≥ 0.2** (Mean ± SD) **					**FA< 0.2** (Mean ± SD) **				
	Normal*	**Abscess***	**σ_1††**	**σ_2††**	**Pvalue†**	**Normal***	**Abscess***	**σ_1**	**σ_2**	**Pvalue†**
λ_1	1.562±0.297	1.556±0.738	0.067	0.165	0.5846	1.286±0.240	0.958±0.316	0.043	0.143	0.0021
λ_2	0.933±0.206	0.832±0.291	0.026	0.070	0.0175	1.049±0.208	0.826±0.265	0.038	0.128	0.0090
λ_3	0.694±0.160	0.481±0.233	0.022	0.076	0.0004	0.816±0.167	0.703±0.226	0.029	0.111	0.0845
MD	1.063±0.179	0.956±0.345	0.038	0.080	0.0867	1.050±0.199	0.829±0.265	0.037	0.127	0.0091
RA	0.249±0.075	0.324±0.144	0.006	0.037	0.0039	0.133±0.012	0.088±0.029	0.002	0.007	<.0001
FA	0.327±0.083	0.398±0.140	0.007	0.036	0.0046	0.185±0.016	0.123±0.040	0.003	0.010	<.0001
CL	0.197±0.092	0.236±0.150	0.007	0.035	0.0414	0.075±0.031	0.052±0.029	0.003	0.004	0.0003
CP	0.151±0.082	0.247±0.133	0.003	0.031	0.0005	0.148±0.062	0.093±0.055	0.004	0.009	<.0001
CS	0.650±0.081	0.517±0.185	0.006	0.050	0.0009	0.776±0.036	0.854±0.053	0.002	0.013	<.0001

* Mean is the mean of the means and SD is the mean of SD's across the patients/controls. ** Units of λ_1, λ_2, λ_3 and MD are 10^{-3} mm^2/sec. † The P-value (computed by SPSS package) in each cell represents the significance of difference of means of normal versus abscess cases for each measure in the corresponding FA sub regions. †† σ_1 and σ_2 are the deviations in means across the controls/patients.



Discussion: Our result show that in high FA (>0.2) regions of abscess cavity the pus cells align or add more to linear or planar diffusion structures; whereas, interestingly, in the low FA (<0.2) regions they contribute to further enhance the spherical diffusion. The statistics tabulated above also shows the variability in λ_1 to be much higher as compared to λ_2 and λ_3 in the abscess lesion, indicating that the heterogeneity of fractional anisotropy in abscess lesion is due principally to the maximum eigenvalue λ_1.

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