International Journal of Radiology Research
www.radiologyjournal.in
E-ISSN: 2663-4562, P-ISSN: 2663-4554
Received: 28-11-2022, Accepted: 13-12-2022, Published: 31-12-2022
Volume 4, Issue 2, 2022, Page No. 16-25

Diffusion tensor imaging in mapping of white matter tracts in relation to brain tumors

Dr. Balaji Varaprasad Mallula, Dr. Eshwar Chandra Nanduri, Dr. Nupur Jajodia, Dr. Dhatri Kallala, Dr. Namratha Reddy Bujala
Department of Radiodiagnosis, Kamineni Hospitals, LB Nagar, Hyderabad, Telangana, India

Abstract
Diffusion Tensor Magnetic Resonance Imaging (DT-MRI), also known as Diffusion Tensor Imaging (DTI), has shown promise as a non-invasive tool for estimating the orientation and quantity of White Matter (WM) tracts *in vivo*. The process of using DTI data to estimate white matter structures is commonly known as tractography. This is a Descriptive study. The present study was conducted on 30 cases of brain tumor who underwent MRI imaging o n a 1.5 – Tesla Siemens Magnetom Symphony scanner. The results of our study are discussed below.

Keywords: wheat, poultry manure, vermiwash, panchagava and yield

Introduction

Over the following 30 years, there was an explosion of technological and scientific advancement in the field of MRI. Scanners became faster and more sensitive, and MR phenomena that initially created problems and artifacts, soon became the basis for new imaging techniques [1]. Improvements in MR imaging hardware and computer capabilities led to faster image acquisition techniques and allowed imaging of rapidly changing physiological processes [2]. For example, with the advent of Echo Planar Imaging (EPI), newer clinical applications such as diffusion, perfusion and Blood Oxygen Level Dependant (BOLD) imaging became available.

Until the advent of DTI, the only reliable techniques used to study axonal pathways were invasive procedures that are only feasible in primate or post-mortem human brains [3-4]. The utility of DTI lies in the many types of images that can be calculated from the information contained in the tensor formalism. These maps can provide scalar information regarding the magnitude and spatial anisotropy of diffusion in a tissue, as well as vector maps that describe directionality of diffusion.

The ability of DTI to quantitatively describe white matter connectivity in the human brain has a variety of clinical applications. The correlation between white matter structural asymmetries and schizophrenia is currently being investigated in group studies [5]. Similar group studies are being conducted to gain an understanding of the progression of white matter tract damage in neuro-degenerative diseases such as Alzheimer's disease [6]. Diffusion anisotropy have been illustrated to have promise in detecting and characterizing brain tumors [7].

DTI has been used to characterize reductions in diffusion anisotropy in regions of severe brain trauma that are theorized to result from tissue swelling [8].

The Physics of DTI

Diffusion of water molecules is isotropic (i.e. free to diffuse in all directions with equal probability). In white matter, water diffusion has a preferred direction presumably because water diffusion across the axons, myelin sheaths, and cytoskeletal elements is hindered and so in white matter, water diffusion is anisotropic. The mathematical formalism used to model this phenomenon is called a tensor, and the imaging used to image anisotropic diffusion is called diffusion tensor MR imaging.

Diffusion tensor MR imaging allows to measure:

- The magnitude of the ADC in the preferred direction of water diffusion.
- Magnitudes perpendicular to the preferred direction
- The orientation of these directions relative to the direction of the applied diffusion gradients.

The pattern of diffusion in any given voxel can be visualized as an ellipsoid, a three-dimension elliptical shape representing the ADC in each direction from the centre. ADC maps depict the overall tendency of water molecules to diffuse within a voxel; they reflect the overall size of diffusion ellipsoid. [9]

In DTI, tensor matrix is subjected to a linear algebraic procedure known as *diagonalization*, the result of which is a set of three *eigenvectors* representing the major, medium, and minor principle axes of the ellipsoid fitted to the data and the corresponding three *eigen values (*$\lambda 1$, $\lambda 2$, $\lambda 3$), which represent the apparent diffusivities along these axes. Any of several anisotropy metrics may be used, one of the most common being *fractional anisotropy* (FA) [10], which derives from the standard deviation of the three eigenvalues and ranges from 0 (isotropy) to 1 (maximum anisotropy)

The direction of maximum diffusivity may be mapped by using red, green, and blue (RGB) color channels with color brightness modulated by FA, resulting in a convenient summary map from which the degree of anisotropy and the local fiber direction can be determined.[11]

Aims and Objectives

Aim

To demonstrate the role of Diffusion Tensor Imaging in mapping of white matter tracts in relation to brain tumor.

Objective

1. To visualize white matter tract involvement in brain tumors.
2. To characterize the variation and extent of white matter tracts involvement in brain tumor.
3. To quantify DTI measures of FA and ADC in patients with diffuse and focal brain tumor.

Materials and Methods

The study group was constituted of 30 patients (23 males and 7 females; age range 23–71years; mean age 46.70 ± 13.54 years) with intracranial neoplasms. Between September 2020 to September 2021, diffusion tensor imaging was performed in 30 patients with brain tumor in a 1.5 – Tesla Siemens Magnetom Symphony scanner in Kamineni Hospitals, L.B. Nagar, Hyderabad, Telengana.

Type of study

Descriptive study

Eligibility

Patients of any age group. Genders Eligible for Study: Both.

Inclusion criteria

All cases of brain tumor who underwent MRI imaging.

Exclusion criteria

- Post operative cases of brain tumor.
- Post radiotherapy cases of brain tumor.
- Patient having history of claustrophobia.
- Patient having history of metallic implants insertion, cardiac pacemakers and metallic foreign body in situ.
- Patient clinically unstable.

Methods

Conventional Magnetic Resonance Imaging

Magnetic resonance imaging was performed on a 1.5 – Tesla Siemens Magnetom Symphony scanner, Erlangen, Germany using a quadrature head coil. Conventional imaging includes the following: T1WI TR 450- 550msec, TE 8 msec in the sagittal, axial planes, T2 WI TR 4800msec TE 127 msec in axial plane, FLAIR TR 9000-10,000 msec TE 127 msec in axial plane.

Diffusion Tensor Imaging

Multidirectional diffusion weighted imaging (MDDW), echo-planar images were acquired with a double spin-echo sequence (230mm x 230mm x 200 mm FOV, TR 2800 msec, TE 98 msec, 4 acquisitions per series). Diffusion encoding were applied along 6 noncollinear directions (b = 1000), and 1 image was acquired without diffusion encoding. FA, ADC, and eigen vector maps were calculated. We transferred the diffusion-tensor imaging data to an offline workstation which is based on the Fiber Assignment by Continuous Tracking (FACT) method.

To aid in the visualization of the fiber tracts, an Red Green Blue (RGB) -orientation color map to demonstrate fiber shape and direction was used. FA and ADC were evaluated in the regions of interest (ROIs) and were compared to contralateral white matter. Cases with bilateral tract involvement were compared with age matched normal controls.

Statistical analysis

Data was entered into Microsoft excel data sheet and was analyzed using SPSS 22 version software. Categorical data was represented in the form of Frequencies and proportions. Continuous data was represented as mean and standard deviation. ANOVA test was used as test of significance to identify the mean difference between more than two groups. Paired t test was used to compare FA and ADC between normal contralateral white matter with other lesions. p value <0.05 was considered as statistically significant.

Results

Patients

The mean age of the patients was 46.7 years (range 23-71 years). In the study most of the patients were in the age group 31 to 40yrs (26.7%) and 51 to 60 years (26.7%). Among the thirty (30) cases, twenty three (23) were men and seven (7) were women.

Brain tumors

Among the thirty patients, seventeen (17) were intra axial lesion and thirteen (13) were extra axial lesion. Three patients had multiple lesions and twenty seven patients had solitary lesion. Most of the cases were solid in nature (22), rest were necrotic (5), solid and cystic, solid and necrotic and cystic. Majority of the cases were showing mass effect (21) in the form of compression on the ventricular system, effacement of cortical sulci or basal cisterns, midline shift or herniation. The most common presentation in patients was seizures.

Extent of White Matter Involvement

White matter pathway involvement was identified in all patients by using anisotropy, color coded DT imaging maps and 3DMR Tractography. Normal white matter pathways demonstrated on DT imaging appeared unaffected in contralateral hemisphere in 27 cases. The WM tracts were color coded in a universal fashion based on their spatial orientation.

Projection fibers were presented by blue color scheme, the commissural fibers were demonstrated by red color, and the association fibers were coded in green. The white matter findings were characterized for each patient and the pattern of involvement [11] by a tumor was classified according to the criteria of displacement, infiltration, disrupted and edematous.

Fourteen (14) cases were showing displacement pattern, six (6) cases were showing edematous and infiltration pattern and rest four (4) were showing disrupted pattern.

Table 1: Age and gender distribution of subjects, Distribution of patients according to number of lesions, Type of lesions Mass effect caused by the lesion, White matter involvement

		Frequency	**Percent**
Age	<30 yrs	4	13.3
	31 to 40 yrs	8	26.7
	41 to 50 yrs	5	16.7
	51 to 60 yrs	8	26.7
	>60 yrs	5	16.7
	Total	30	100.0
		Frequency	Percent
Gender	Female	7	23.3
	Male	23	76.7
	Total	30	100.0
		Frequency	Percent
No of lesions	One lesion	27	90.0
	Multiple lesion	3	10.0
	Total	30	100.0
		Frequency	Percent
Type of lesions	Solid	22	73.3
	Necrotic	5	16.7
	Cystic	1	3.3
	Solid and necrotic	1	3.3
	Solid and cystic	1	3.3
	Total	30	100.0
		Frequency	Percent
Mass Effect	Nil	9	30
	Present	21	70
	Total	30	100.0
		Frequency	Percent
White matter Involvement	Destroyed	4	13.3
	Displacement	14	46.6
	Edematous	6	20.0
	Infiltration	6	20.0
	Total	30	100.0

Table 2: Number of intra and extra axial lesions

Total number of lesions	**Intra axial**	**Extra axial**
30	17	13

Table 3: Comparison of FA and ADC in Displaced white matter lesions

		Mean	Std. Deviation	N	t Value	p value
FA	Contralateral Normal White Matter	0.496	0.119	14	10.542	<0.0001**
	Tumor	0.152	0.091	14		
	Contralateral Normal White Matter	0.505	0.124	12	7.846	<0.0001**
	Tumor Border	0.255	0.145	12		
	Contralateral Normal White Matter	0.500	-	1	-	-
	Edema	0.170	-	1		
	Contralateral Normal White Matter	0.496	0.119	14	2.131	0.053
	Peritumoral white matter	0.451	0.103	14		
ADC	Contralateral Normal White Matter	0.723	0.033	14	-2.052	0.061
	Tumor	1.144	0.079	14		
	Contralateral Normal White Matter	0.716	0.032	13	-3.354	0.006**
	Tumor Border	1.015	0.082	13		
	Contralateral Normal White Matter	0.75	0.04	1	-	-
	Edema	1.70	0.03	1		
	Contralateral Normal White Matter	0.72	0.033	14	0.767	0.457
	Peritumoral white matter	0.78	0.055	14		

** p value <0.05 and significant

Table 4: Comparison of FA and ADC in Destroyed white matter lesions

		Mean	Std. Deviation	N	t Value	p value
FA	Contralateral Normal White Matter	0.475	0.065	4	10.241	0.002**
	Tumor	0.1025	0.016	4		
	Contralateral Normal White Matter	0.475	0.065	4	2.088	0.128
	Tumor Border	0.255	0.11	4		
	Contralateral Normal White Matter	0.48	0.035	2	5.667	0.111
	Edema	0.14	0.0185	2		
	Contralateral Normal White Matter	0.475	0.065	4	2.543	0.084
	Peritumoral white matter	0.2525	0.182	4		
ADC	Contralateral Normal White Matter	0.72	0.052	4	-1.466	0.239
	Tumor	1.16	0.07	4		
	Contralateral Normal White Matter	0.72	0.052	4	-1.318	0.279
	Tumor Border	1.125	0.13	4		
	Contralateral Normal White Matter	0.685	0.025	2	-5.968	0.106
	Edema	1.61	0.03	2		
	Contralateral Normal White Matter	0.72	0.0525	4	-1.748	0.179
	Peritumoral white matter	0.822	0.045	4		

** p value <0.05 and significant

Table 5: Comparison of FA and ADC in Infiltrated white matter lesions

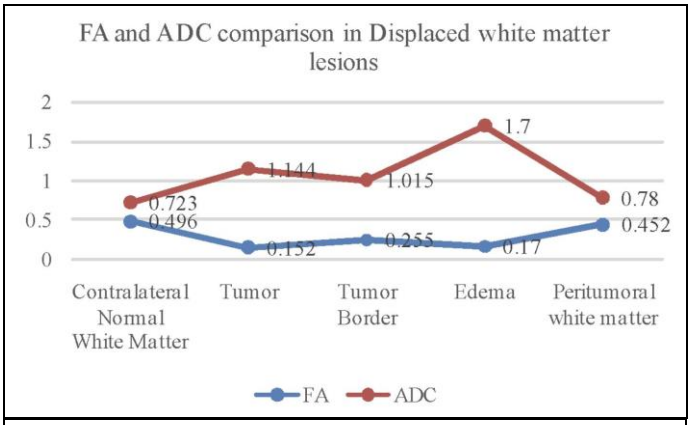
		Mean	N	SD	t value	p value
FA	Contralateral Normal White Matter	0.50	6	0.126	4.252	0.008**
	Tumor	0.16	6	0.098		
	Contralateral Normal White Matter	0.50	6	0.126	4.137	0.009**
	Tumor Border	0.22	6	0.055		
	Contralateral Normal White Matter	0.58	3	0.104	10.769	0.009**
	Edema	0.12	3	0.036		
	Contralateral Normal White Matter	0.50	6	0.126	1.374	0.228
	Peritumoral white matter	0.42	6	0.083		
ADC	Contralateral Normal White Matter	0.76	6	0.075	-3.716	0.014**
	Tumor	1.15	6	0.304		
	Contralateral Normal White Matter	0.76	6	0.075	-4.139	0.009**
	Tumor Border	1.086	6	0.201		
	Contralateral Normal White Matter	0.72	3	0.081	-6.969	0.02**
	Edema	1.68	3	0.156		
	Contralateral Normal White Matter	0.76	6	0.075	-.332	0.753
	Peritumoral white matter	0.77	6	0.052		

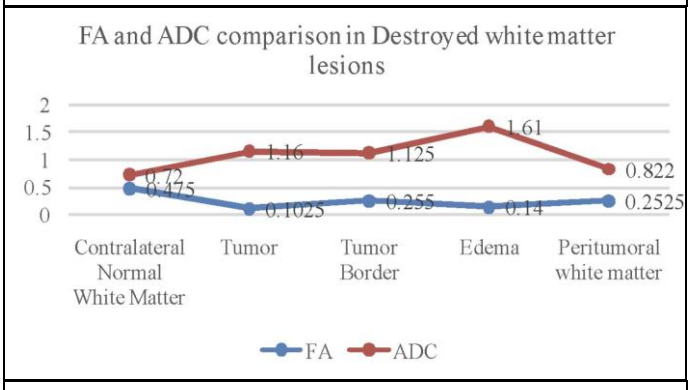
** p value <0.05 and significant

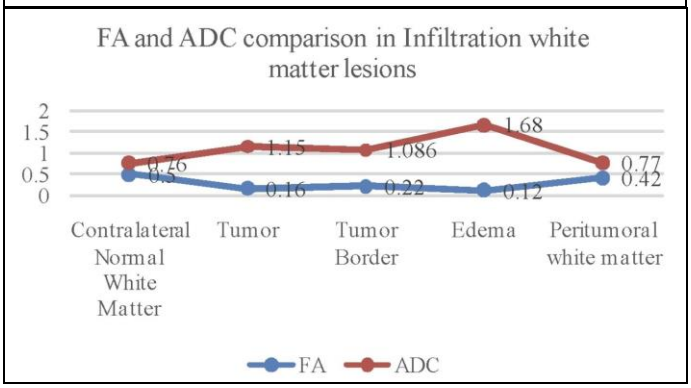
Table 6: Comparison of FA and ADC in Edematous white matter lesions

		Mean	Std. Deviation	N	t value	p value
FA	Contralateral Normal White Matter	0.488	0.213	6	4.697	0.005**
	Tumor	0.061	0.015	6		
	Contralateral Normal White Matter	0.497	0.165	4	5.021	0.015**
	Tumor Border	0.066	0.046	4		
	Contralateral Normal White Matter	0.600	0.201	3	4.670	0.043**
	Edema	0.166	0.041	3		
	Contralateral Normal White Matter	0.488	0.213	6	1.773	0.136
	Peritumoral white matter	0.400	0.141	6		
ADC	Contralateral Normal White Matter	0.778	0.054	6	-2.046	0.096
	Tumor	1.400	0.732	6		
	Contralateral Normal White Matter	0.770	0.031	4	-4.233	0.024**
	Tumor Border	1.115	0.176	4		
	Contralateral Normal White Matter	0.800	0.062	3	-11.536	0.007**
	Edema	1.643	0.075	3		
	Contralateral Normal White Matter	0.778	0.054	6	-1.306	0.248
	Peritumoral white matter	1.068	0.535	6		

** p value <0.05 and significant







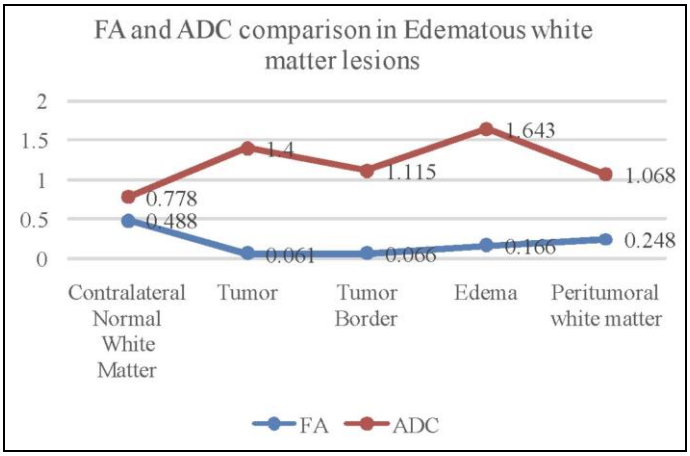


Fig 1: FA and ADC comparison in displaced, destroyed, infiltrative and edematous white matter lesions.

Cases

Case 1

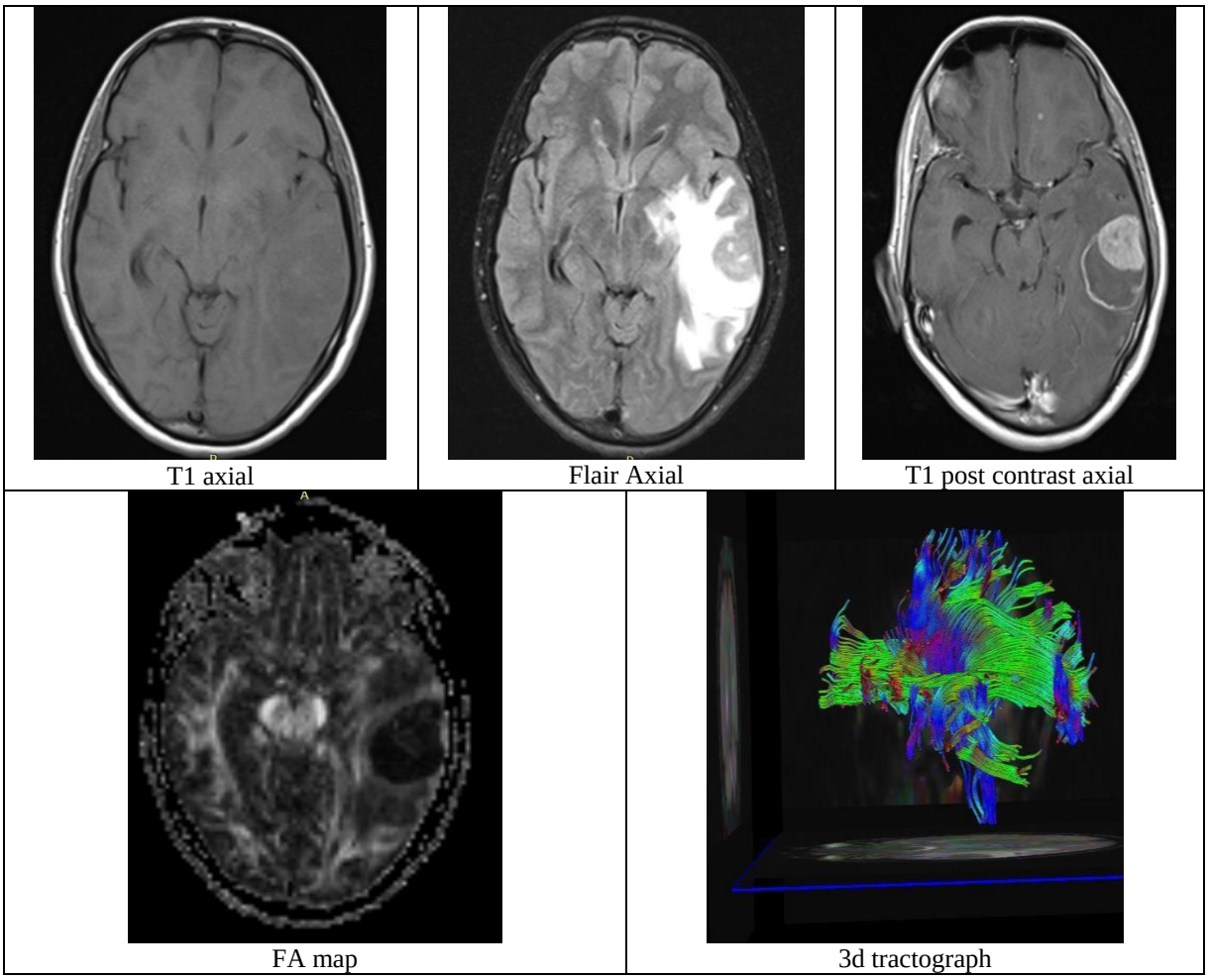


Fig 2: A 36 year old male patient with known case of malignant lesion in right hilar region of lung and brain metastases: MRI shows welldefined T1 hypointesne FLAIR heterogeneously hyperintense lesion in left temporal lobe, with moderate perilesional edema. Post contrast enhancement is noted. DTI shows edematous peritumoral white matter tracts, increase in ADC in edema 1.6±0.04 x 10^{-3} mm^2/sec,as compared to contralateral white matter 0.78±0.02 x 10^{-3} mm^2/sec.

Case 2

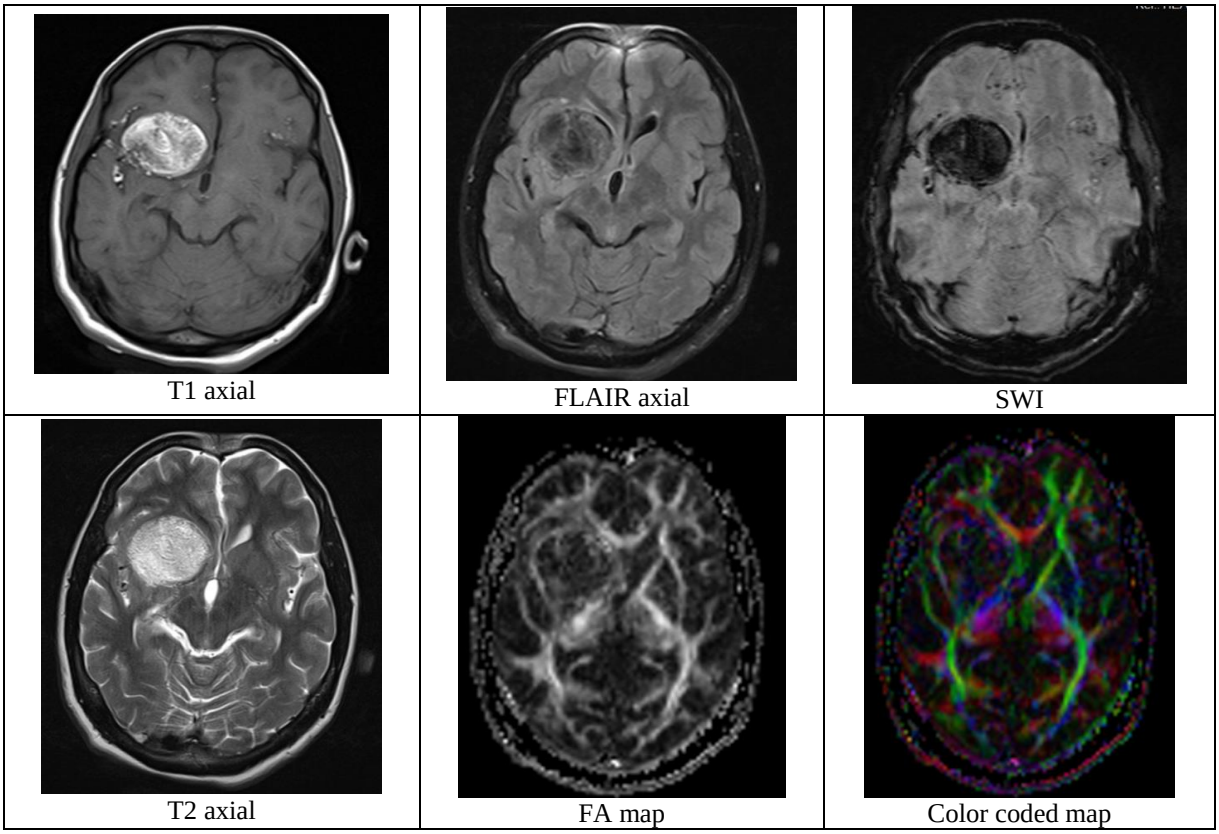


Fig 3: A twenty four year old female patient presented with 1 episode of seizure. MRI shows T1/T2 hyperintense lesion, hypointense in FLAIR in right frontal region. The lesion is blooming on SWI sequence. Multiple sulcal space T1 hyperintensity, c/w ruptured dermoid cyst. DTI shows displacement of right internal, external capsule and corticospinal tract.

Case 3

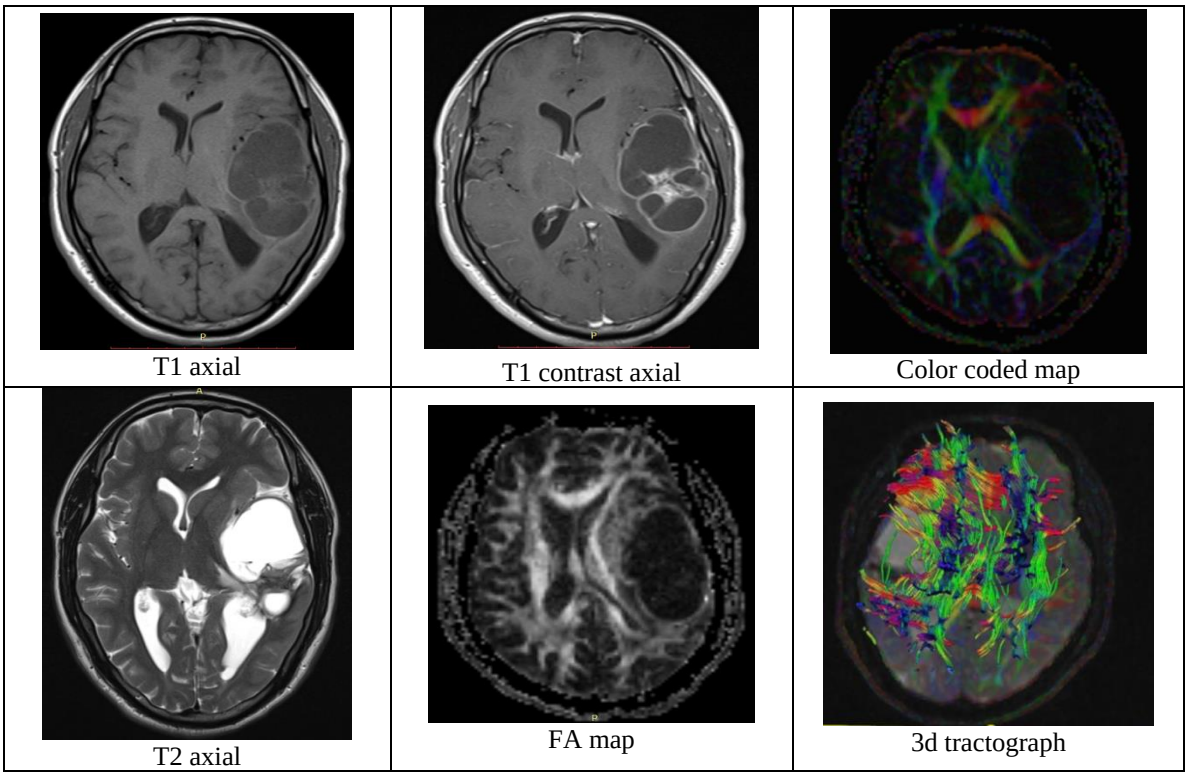


Fig 4: A Thirty year old male patient with cystic meningioma: MRI shows a large lobulated extra axial T1 hypointense T2 hyperintense lesion in left temporo parietal region with multiple T2 hypointense internal septations. Post contrast study shows rim enhancement. The lesion is showing displacement of internal, external capsule, inferior occipitofrontal fasciculus, corona radiata, corticospinal tracts. Significant reduction in FA was noted within the lesion and in perilesional edema.

Case 4

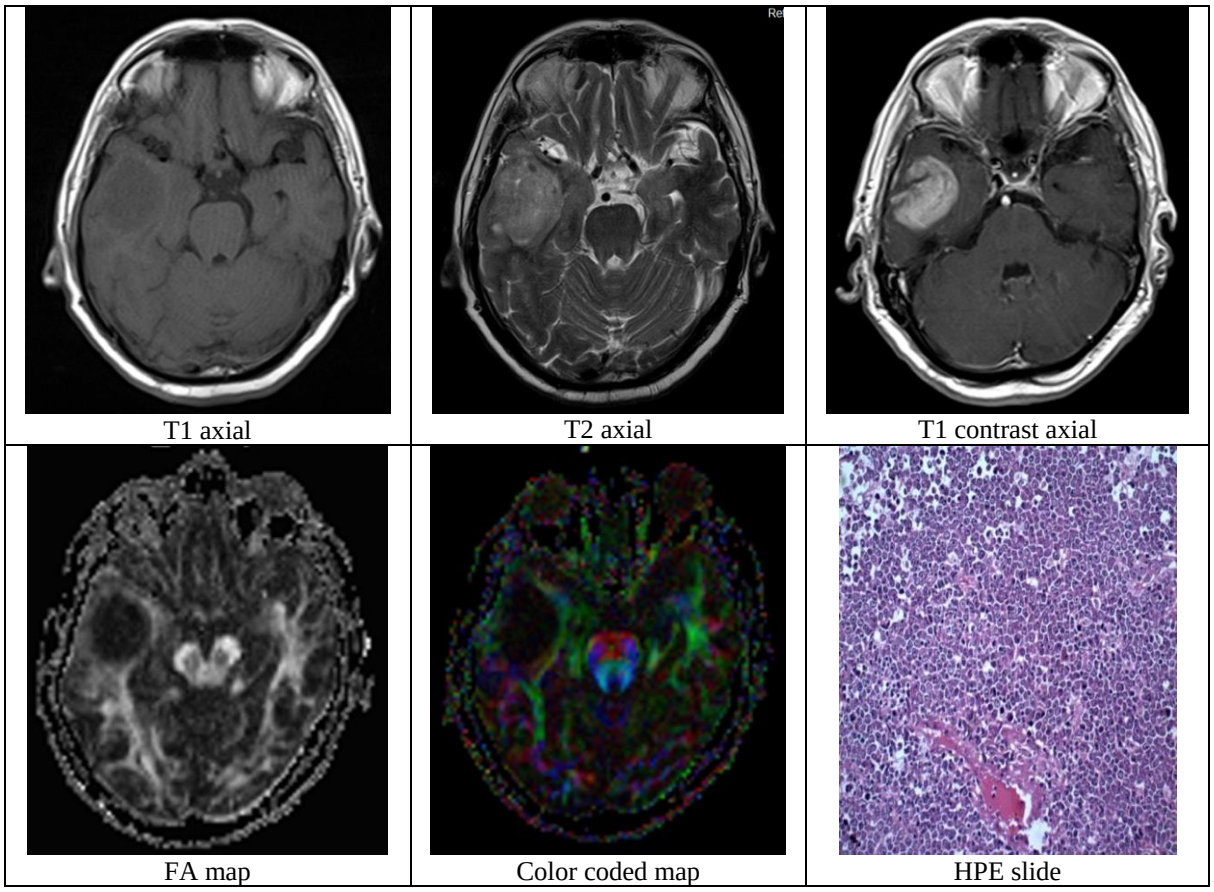


Fig 5: A sixty two year old male patient with primary CNS lymphoma: MRI shows a well defined T1 hypointense T2 heteogeneously hyperintense lesion in right temporal lobe. Post contrast moderate enhancement is seen. On DTI, the lesion is displacing right inferior longitudinal fasciculus and uncinate process. Histophologically proven as Diffuse large B cell lymphoma.

Case 5

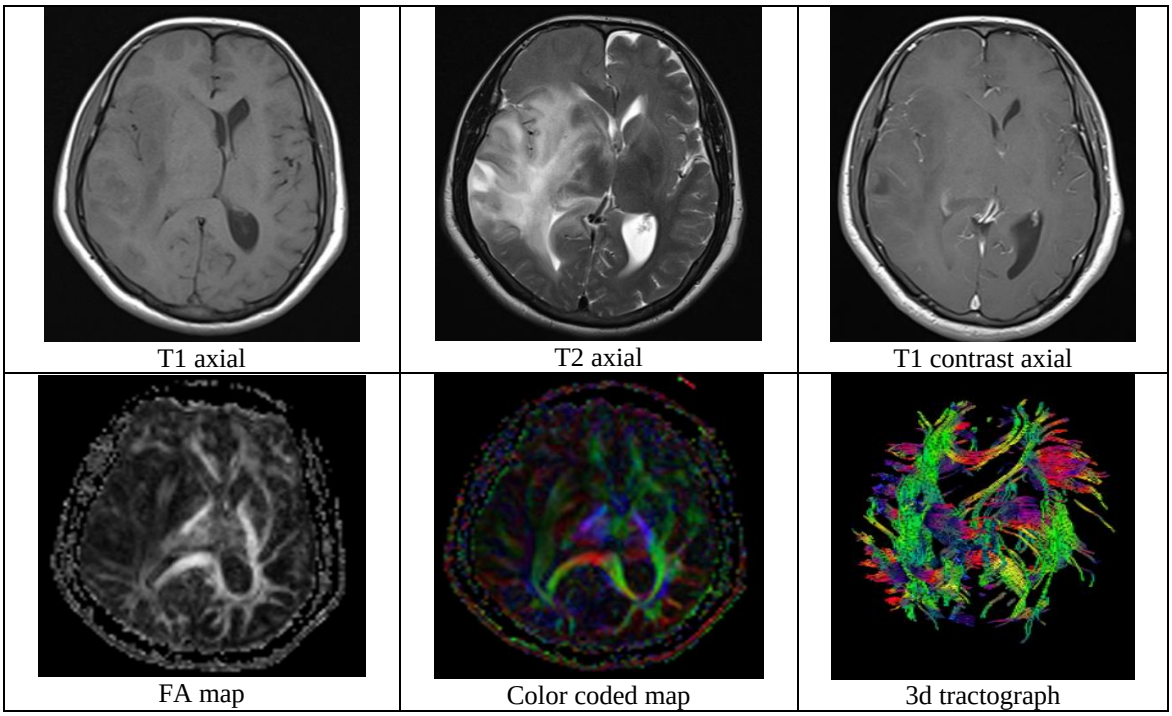


Fig 6: A thirty six year old male patient with complaints of seizures, MRI shows a large T1 hypointense T2 hyperintense lesion in right temporal and parietal lobes with focal irregular contrast enhancement. Findings are s/o low grade glioma. DTI shows decreased FA with infiltration of peritumoral white matter. FA 0.12±0.01, contralateral normal white matter 0.33±0.05.

Case 6

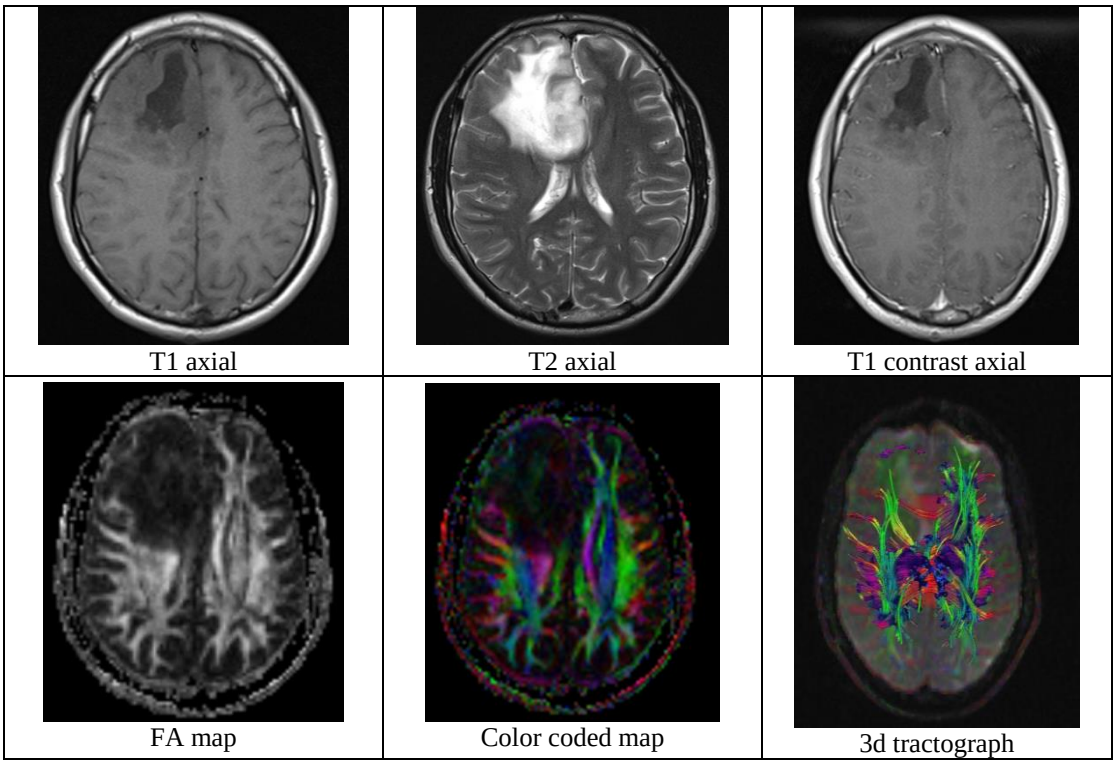


Fig 7: A twenty three old male patient with WHO grade IV glioblastoma multiforme: MRI shows a large T1 hypointense T2 hyperintense lesion, post contrast showing central non enhancing necrotic area. DTI shows disruption of superior, inferior occipitofrontal fasciculus, corticospinal tract**.**

Discussion

MR diffusion imaging has been used to study water mobility in normal brain tissue (22, 23), cerebral infarction (23), multiple sclerosis (24), brain tumor (25-29), and brain abscesses (29, 30) and to differentiate between arachnoid cysts and epidermoid cysts[31] and other diseases [28, 29, 32, 33].

White matter tractography based on diffusion tensor imaging has become a well-accepted noninvasive tool for exploring the white matter architecture of the human brain *in vivo.* [46-48]

The aim of the study is to assess the role of diffusion tensor imaging in brain tumor. Delineation of white matter tract plays a crucial role in neurosurgery.

Extensive tumor resection can reduce the risk of relapse (particularly gliomas with low grade malignancy) and allow subsequent radiotherapy or chemotherapy to be more effective. On the other hand, sparing ‘‘functionally relevant’’ zones and therefore preservation of motor, visual or language functions significantly improves the quality of life of these patients [34, 35, 36].

DTI is a noninvasive imaging technique that provides information about tissue microstructure and architecture by measuring the average and directional variation of water diffusivity for a given voxel in terms of ADC and FA, respectively.

DTI provides information on the directionality of water molecules at the cellular level, thus indicating the orientation of fiber tracts. Diffusion tensor calculations permit the characterization of diffusion in heterogeneously oriented tissue. The spatial orientation of myelinated fiber tracts can then be represented as distinct white matter maps in easily read, color- coded directional maps [12].

The most significant use of DTI, in particular, is to preoperatively confirm the integrity and location of displaced white matter tracts. White matter tracts may be pathologically altered by the tumor in several ways; specifically, they may be displaced, infiltrated by tumor and/or edema, or destroyed. Four imaging patterns were identified that presumably reflected these alterations on FA-weighted directional color maps [37].

Unlike ADCs, anisotropy values differ according to the specific WM site studied [38]. For this reason, we did not compare solely mean anisotropy values for each brain region, but rather we also compared the anisotropy values with those in a corresponding region in essentially the same WM location in the opposite hemisphere. In all the thirty (30) cases white matter were characterized based on fractional anisotropy, fiber orientation and direction into four categories. Out of thirty cases, fourteen (14) cases showed displacement of white matter in which two(2) cases had intra axial lesion and twelve (12) cases had extra axial lesion. Six(6) cases showed edematous pattern, in which tumor in five(5) cases were intra axial and one (1) case was extra axial in location. Six (6) cases showed infiltrative pattern and four(4) cases showed disruption of white matter, in which all the

tumor were intra axial in location. Fractional anisotropy and ADC values were calculated in four to five region of interest similar to a study performed by Kono *et al* [41].

Region of interest was placed in the solid component of the tumor or in tumor centre, tumor border, perilesional white matter and contralateral white matter. Nine out of the total cases showed perilesional edema, so additional region of interest was placed in perilesional edema.

Conclusion

The following conclusions could be drawn from the study - The effect of brain tumor on white matter pathways is much better evaluated with the aid of DTI than on conventional MRI.

The white matter tracts were characterized based on anisotropy, fiber orientation or direction into four patterns – displaced, infiltration, edematous and destroyed. There can be one or more of four distinct patterns of white matter tracts alteration by the tumor. Low anisotropy seen in tumor in all the cases in comparison with contralateral normal white matter with increased apparent diffusion coefficient in peri tumoral edema.

Limitations

- Firstly, there is no ‘‘gold standard’’ for *in vivo* tractography. As DTI is the only method that permits the calculation and visualization of fiber tracts trajectories *in vivo*.
- Secondly, DTI is a user defined process. In particular, the tracking results were found to vary according to FA threshold and numbers of sampling in a voxel length. Choosing different parameters can produce different fibers and tracked volumes are also dependent on the size and locations of the seed ROIs.

References

1. Guye M, Parker G, Symms M, Boulby P, Wheeler-Kingshott C, Salek-Haddadi A *et al*. Combined functional MRI and tractography to demonstrate the connectivity of the human primary motor cortex *in vivo*. Neuro Image,2003:19(4):1349-1360.
2. Niznikiewicz M, Kubicki M, Shenton M. Recent structural and functional imaging findings in schizophrenia. Current Opinion in Psychiatry,2003:16(2):123-147.
3. Taylor W, Hsu E, Krishnan K, MacFall J. Diffusion tensor imaging: background, potential, and utility in psychiatric research. Biological Psychiatry,2004:55(3):201-207.
4. Zhang S, Bastin M, Laidlaw D, Sinha S, Armitage P, Deisboeck T. Visualization and analysis of white matter structural asymmetry in diffusion tensor MRI data. Magn Reson Med,2003:51(1):140-147.
5. Barboriak D. Imaging of brain tumors with diffusion-weighted and diffusion tensor MR imaging. Magnetic Resonance Imaging Clinics of North America,2003:11(3):379-401.
6. Stanley Lu, Daniel Ahn, Glyn Johnson, Soonmee Cha. Peritumoral Diffusion Tensor Imaging of High-Grade Gliomas and Metastatic Brain Tumors. Am J Neuroradiol,2003:24:937-941.
7. Stadlbauer A, Ganslandt O, Buslei R, Hammen T, Gruber S, Moser E *et al*. Gliomas: Histopathologic Evaluation of Changes in Directionality and Magnitude of Water Diffusion at Diffusion-Tensor MR Imaging 1. Radiology,2006:240(3):803-810.
8. Helton KJ, Phillips NS, Khan RB, Boop FA, Sanford RA, Zou P, *et al*. Diffusion Tensor Imaging of Tract Involvement in Children with Pontine Tumors. Am J Neuroradiol,2006:27:786-93.
9. Wang W, Steward C, Desmond P. Diffusion Tensor Imaging in Glioblastoma Multiforme and Brain Metastases: The Role of p, q, L, and Fractional Anisotropy. American Journal of Neuroradiology,2008:30(1):203-208.
10. Ibrahim A, Gomaa M, Sakr H, Elzaher Y. Role of diffusion tensor imaging in characterization and preoperative planning of brain neoplasms. The Egyptian Journal of Radiology and Nuclear Medicine,2013:44(2):297-307.
11. Noguchi K, Watanabe N, Nagayoshi T, *et al*. Role of diffusionweighted echo-planar MRI in distinguishing between brain abscess and tumour: a preliminary report. Neuroradiology,1999:41:171-174.
12. Romano A, Ferrante M, Cipriani V, Fasoli F, Andrea GD, Fantozzi LM, *et al*. Role of magnetic resonance tractography in the preoperative planning and intraoperative assessment of patients with intra-axial brain tumours. Radiol med,2007:112:906-20.
13. Fujiwara N, Sakatani K, Katayama Y. Evoked-cerebral blood oxygenation changes in false negative activations in BOLD contrast functional MRI of patients with brain tumors. Neuroimage,2004:21:1464-71.
14. Yu CS, Li KC, Xuan Y, Ji XM, Qin W. Diffusion tensor Tractography in patients with cerebral tumors: a helpful technique for neurosurgical planning and postoperative assessment. Eur J Radiol,2005:56:197-204.