Research Article

To Estimate Fractional Anisotropy and Mean Diffusivity Values of various brain pathologies on Magnetic Resonance Diffusion Tensor Imaging

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ABSTRACT

Introduction and Aim: To assess Diffusion Tensor Imaging (DTI) role in distinguishing neoplastic from non-neoplastic brain lesions.

Materials and Methods: We retrospectively collected Magnetic resonance (MR) brain data from consecutive patients scanned between January and May 2021, identifying those with neoplastic and non-neoplastic brain lesions from Picture Archiving Communicating System (PACS). DTI sequences were performed on patients with intracranial lesions and a subset of control patients with normal MRI findings. The values of Fractional Anisotropy (FA) and Mean Diffusivity (MD) were obtained from both lesions and Normal Appearing White matter (NAWM) for comparison.

Results: We analysed 64 samples (51.5 % male, 48 % female) with various Intracranial lesions. Mean FA values in lesions were 0.5925 and in NAWM were 0.6466, while mean MD values were 0.5816 mm^2/sec in lesions and 0.6954 mm^2/sec in NAWM. Statistical analysis showed a significant decrease in both FA and MD of Intracranial lesions compared to NAWM ($p < 0.001$).

Conclusion: FA and MD values were lower in intracranial lesions compared to NAWM, except for metastases, which exhibited slight increases in both FA and MD values. These results highlight the utility of FA and MD values in distinguishing between types of intracranial lesion. Integrating MR DTI sequences into imaging protocols can improve diagnostic accuracy for individual cases of intracranial pathology.

Keywords: Diffusion Tensor Imaging, Fractional anisotropy, Mean diffusivity, Normal appearing white matter, Intracranial lesions.

1. INTRODUCTION

Magnetic Resonance is an important modality to assess brain pathologies. Diffusion sequence is commonly used in brain. Diffusion imaging leverages the variability in the "Brownian Motion" of water molecules within brain tissues. [1].

DTI takes advantage of the varying rates and directions of water molecule diffusion, which depend on the orientation of fiber bundles. Specifically, water molecules diffuse more easily along the direction of the fiber bundles and less so perpendicular to them. This technique is used to map and analyse the three-dimensional diffusion of water based on spatial location. Anisotropic nature of diffusion can be exploited for providing critical information about the microscopic structural organisation of tissue, particularly the white matter (WM) within the central nervous system (CNS) [2] [19].

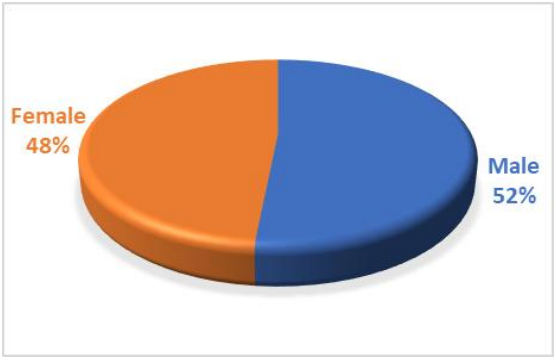
The primary direction of the diffusion tensor can provide insights into the white matter connectivity of the brain. Diffusion tensor

imaging is a complimentary tool and an important adjunct to the conventional MRI [17]. FA and MD are two important parameters usually taken, when studying DTI of Brain [3]. FA and MD values are useful in grading of intracranial mass lesions. Tractography is useful to assess whether the white matter tracts are destroyed or displaced [8].

2. MATERIALS & METHODS

2.1 Materials

We retrospectively retrieved the data of 64 patients of male 33 patients and female 31 patients in MRI Brain examinations performed from January 2021 to May 2021(Graph 1). The data were retrieved from PACS (Picture archiving communicating system). All MRI Brain examinations were performed in GE SIGNA HDXt1.5T MRI system. A dedicated Neurovascular array (8 channels) coil and Head matrix (48 channels) coil were used for imaging. Detailed history for all the patients who underwent MRI was collected from the medical records. These images were retrieved from PACS and required data were collected in format mentioned in the proforma. Conventional MRI sequences were done for all the brain examinations which included three plane localizer, T2W Fat suppressed Axials, Diffusion weighted Axials, FLAIR Coronals, T1W Sagittal and Gradient Axials. Additionally, DTI sequence was performed in patients with various intracranial lesions [9]. DTI sequence was performed in the 64 control patients who had normal imaging features on MRI. Mean FA and MD values were measured in the lesion.MD from NAWM were also obtained for the purpose of comparison.



Graph 1: Shows Gender Distribution

The acquired data were analyzed. DTI images were transferred to Advantages workstation and Functool Software version 4.4 was used for post-processing. After post-processing, two similar sized Region of Interest (ROI) were positioned within the lesion and in NAWM were displayed. FA and MD values were noted down for all the patients (Table 1).

Table 1: Shows percentage of intracranial lesions

S.no	Intracranial lesions	No of cases	Percentage %
1	Meningioma	8	12.5
2	Tuberculoma	8	12.5
3	Neurocysticercosis	8	12.5
4	Low Grade Glioma	8	12.5
5	High Grade Glioma	8	12.5
6	Infarct	8	12.5
7	Metastasis	8	12.5
8	Mesial Temporal Sclerosis	2	3.12
9	Macroadenoma	2	3.12
10	Tuberous sclerosis	2	3.12
11	Haemangioma	2	3.12

2.2 Data Collection

MRI data was performed only in indicated patients who were referred to Radiology for MRI Brain examination.

Inclusion Criteria: MRI data of all patients with findings of neoplasms and non-neoplastic lesions were included.

Exclusion Criteria: MRI data of patients with history of trauma and surgery were not included

3. STATISTICAL ANALYSIS

Statistical analysis (one way ANOVA) showed a significant decrease in both FA and MD of intracranial lesions compared to NAWM (Table 2). One way ANOVA showed that the reduction in mean FA and mean MD of intracranial lesions, compared to NAWM, was Statistical highly significant, with a p-value of 0.000. (Table 3).

Table 2: A one-way analysis of the mean values of FA and MD in intracranial lesions compared to NAWM

		Sum of Square	DF	Mean square	F	Significance
Fractional Anisotropy	Between group	3.87	7	1.752	13.671	0
	Within group	2.062	41	0.045		
	Total	5.932	48			
Mean Diffusivity	Between group	12.263	7	0.533	38.619	0
	Within group	2.314	41	0.4		
	Total	14.577	48			

Table 3: ANOVA between two (FA & MD) Groups and within two (FA&MD) groups

						95% CI	
Variable	**Group**	**No**	**MEAN**	**SD**	**SE**	**Upper bound**	**Lower bound**
Fractional Anisotropy	Intracranial lesions	49	0.6876	0.1489	0.4709	0.581	0.7941
	NAWM	49	0.6903	0.3198	0.4163	0.607	0.7736
Mean Diffusivity	Intracranial lesions	49	0.5797	0.2363	0.7472	0.4106	0.7587
	NAWM	49	0.8133	0.5013	0.6526	0.6826	0.9439

Post Hoc Tests

Mean Diffusivity

The post hoc Tukey HSD test for mean diffusivity (MD) highlights significant differences among specific groups. Participants 2 and 7 exhibited notably higher MD values than Participants 1, 3, 4, 5, 6, and 8 ($p < 0.05$). This indicates that these two groups have distinct diffusion properties, possibly representing different types of brain lesions. Conversely, Participants 3, 4, 5, and 6 showed no significant differences among themselves, suggesting a similar diffusion pattern. Participants 1 and 7 displayed lower MD values compared to Participant 2, further emphasizing the heterogeneity in MD values across different lesion types. These findings reinforce that MD values can help differentiate between certain brain pathologies, as distinct groups exhibit significant variations in diffusivity. The results also suggest that certain lesion types (e.g., metastases) may have higher MD values, whereas other lesion types may cluster together with similar MD characteristics.

Table 4: Significant Mean Diffusivity Differences

Participant	Compared Participant	Mean Difference	p-value	Significance
1	2	-1.089	0	Yes
1	7	-0.92	0	Yes
2	3	1.057	0	Yes
2	4	1.081	0	Yes
2	5	1.224	0	Yes
2	6	1.343	0	Yes
2	8	0.78	0	Yes
3	7	-0.888	0	Yes
4	7	-0.913	0	Yes
5	7	-1.055	0	Yes
5	8	-0.444	0	Yes
6	7	-1.174	0	Yes
6	8	-0.563	0	Yes
7	8	0.611	0	Yes

This table includes only the significant results ($p < 0.05$).

Fractional Anisotropy

The post hoc analysis of fractional anisotropy (FA) using Tukey's HSD test revealed significant differences among specific groups. Notably, Participant 7 exhibited a significantly higher FA value than Participants 1, 2, 3, 4, 5, and 6 ($p < 0.001$), suggesting that this group had a distinct diffusion pattern, potentially indicative of a different pathology or lesion composition. Additionally, Participant 2 differed significantly from Participant 6 ($p < 0.05$), demonstrating variability in FA values even among non-neoplastic and neoplastic lesions. A further significant difference between Participants 7 and 8 ($p < 0.001$) underscores the heterogeneity in FA values across different brain lesion groups.

Table 5: Significant Fractional Anisotropy Differences

Participant	Compared Participant	Mean difference	p – value	Significance
1	7	-0.621	0.000*	Significant
2	6	0.351	0.038*	Significant
2	7	-0.534	0.000**	Significant
3	7	-0.731	0.000**	Significant
4	7	-0.781	0.000**	Significant
5	7	-0.839	0.000**	Significant
6	7	-0.886	0.000**	Significant
7	8	0.554	0.000**	Significant

This table includes only the significant results ($p < 0.05$).

Comparison of Post Hoc Results and Conclusion

The post hoc analysis of Mean Diffusivity (MD) and Fractional Anisotropy (FA) values reveals notable differences between various brain lesion groups, highlighting the potential of Diffusion Tensor Imaging (DTI) in differentiating neoplastic from non-neoplastic pathologies.

For MD, the Tukey HSD test identified significant differences among specific groups, with Participants 2 and 7 exhibiting higher MD values than Participants 1, 3, 4, 5, 6, and 8 ($p < 0.05$). This suggests that these two groups represent lesions with increased diffusivity, potentially indicating tumour types or pathologies with a greater degree of tissue disorganization, necrosis, or extracellular oedema. Conversely, Participants 3, 4, 5, and 6 did not show significant differences among themselves, implying that these lesion types may share similar diffusion characteristics, possibly related to similar histological compositions or pathophysiological processes. Furthermore, Participants 1 and 7 exhibited lower MD values than Participant 2, indicating that while some lesions show increased extracellular space

(hence, higher MD), others may demonstrate restricted diffusion due to densely packed cellular structures, as seen in high-grade tumours or abscesses.

In comparison, the FA values demonstrated a more pronounced differentiation among the groups. The post hoc analysis revealed that Participant 7 had significantly higher FA values than Participants 1, 2, 3, 4, 5, and 6 ($p < 0.001$), indicating a distinct diffusion profile. This suggests that the anisotropy of diffusion in this lesion type is markedly different from others, potentially due to preserved or aligned white matter structures. Additionally, Participant 2 showed a significant FA difference compared to Participant 6 ($p < 0.05$), suggesting variability even within the non-neoplastic and neoplastic lesion categories. The significant difference between Participant 7 and Participant 8 ($p < 0.001$) further supports the idea that some brain lesions, such as certain tumors or infiltrative processes, may retain higher FA values due to their microstructural organization, whereas others, such as cystic lesions or gliomas, exhibit more isotropic diffusion patterns.

The post hoc analysis confirms that DTI-derived FA and MD values play a critical role in differentiating intracranial lesions. While both parameters provide valuable diagnostic insights, FA appears to be more effective in distinguishing between lesion types due to its ability to assess microstructural integrity. MD variations provide additional information about tissue characteristics, particularly regarding extracellular water content and diffusion restriction. The findings from this study reinforce the importance of incorporating DTI sequences into routine MRI protocols, as they enhance diagnostic accuracy and improve the ability to classify brain lesions based on their diffusion characteristics. This, in turn, can aid in better clinical decision-making, treatment planning, and prognostic assessment for patients with brain pathologies.

4. RESULTS & DISCUSSION

4.1 Results

We have totally taken 64 samples were analysed. Out of these 64, 33 male (51.5 %) of patients and 31 female (48%) of patients (Graph 1). The patients' ages ranged from 6 to 82 years, with the highest incidence observed in 16 patients noted in the 3rd decade category.

4.1.1 Distribution of Intracranial Lesions

The study showed intracranial findings of Meningioma (n=8) 12.5%, Tuberculoma (n=8) 12.5%, Neurocysticercosis (n=8) 12.5%, Low Grade Glioma (n=8) 12.5%, High Grade Glioma (n=8) 12.5%, Infarct (n=8) 12.5%, Metastases (n=8)12.5%, Mesial Temporal Sclerosis (n= 2) 3.12%, Macroadenoma (n=2) 3.12%,Tuberous sclerosis (n=2) 3.12% and Haemangioma (n=2) 3.12% .

4.1.2 Mean FA Values in Lesions and NAWM (N=64)

The mean FA values in intracranial lesions was 0.5925 and NAWM was 0.6466. These values were compared. The mean FA of the study group appeared to be reduced when compared to the mean FA of NAWM.

4.1.3 Mean MD Values in Lesions and NAWM (N=64)

The mean MD values in intracranial lesions was 0.5816 mm2/sec and NAWM was 0.6954 mm2/sec. Similarly, the mean MD values within the study group (intracranial lesions) were reduced when compared with mean MD values of NAWM.

4.2 Discussion

Meningioma: The Raymond Y. Huang *et al.,* [4] study was correlated with our study, where the values of FA and MD in the lesion and NAWM were mentioned (Table 4). In our study, the FA value was significantly reduced, indicating a notable decrease in water motion organization, whereas the MD value was higher in the lesion, suggesting more disorganized microscopic water motion in Grade I meningiomas.

Tuberculoma: The mean FA and mean MD in tuberculomas were significantly lower compared to the mean FA and mean MD values of NAWM [11][12] (Table 4).

Neurocysticercosis: Rakesh Ke Gupta *et al.,* [5] study showed that there was a successive decrease in the MD values of NCC lesions as they evolved from vesicular to granular nodular change. However, our study demonstrated

significantly lower values compared to the mean FA and mean MD of NAWM. (Table 4).

Gliomas: The study by T. Ogasawara *et al.*, [6] [10] [20] [15] found that the FA value for low-grade gliomas was significantly lower than that for high-grade gliomas, which aligns with our findings[14] .In our study, the mean FA and mean MD in LGG were significantly reduced compared to those in NAWM (Tables 7 & 8). Conversely, for HGG [16], the mean FA and MD values were also significantly reduced relative to NAWM. (Table 4).

Infarct: Ziqian Chen *et al.*, [7] reported that the FA value at the infarct site was significantly lower than the FA value of the corticospinal tract on the contralateral side. In our study, the mean FA value in the lesions was reduced compared to both the mean FA and mean MD of NAWM [21] (Table 4).

Metastasis: The mean FA and mean MD were slightly higher compared to the values of mean FA and mean MD in NAWM [10] (Table 4).

Mesial temporal sclerosis: The mean FA and MD values were nearly identical to those of NAWM (Table 4).

This study had only two finding each of macroadenoma, tuberous sclerosis and haemangioma and two findings of mesial temporal sclerosis, hence, comparison was not possible, and it was difficult to infer information regarding the FA and MD values in such lesions.

Table 6: Shows Intracranial lesions of mean FA and MD values

	Intracranial lesions		**NAWM**	
	Mean FA Values	**Mean MD Values mm^2/sec**	**Mean FA Values**	**Mean MD Values mm^2/sec**
Meningioma	0.47	0.44	0.62	0.61
Tuberculoma	0.57	0.6	0.61	0.77
Neurocysticercosis	0.53	0.55	0.6	0.58
Low Grade Glioma	0.42	0.32	0.53	0.46
High Grade Glioma	0.66	0.79	1.3	1.52
Infarct	0.67	0.82	0.77	1.66
Metastasis	0.75	0.88	0.6	0.66
Mesial Temporal Sclerosis	0.6	0.73	0.69	0.64
Macroadenoma	0.71	0.57	0.64	0.43
Tuberous Sclerosis	0.53	0.12	0.44	0.19
Haemangioma	0.45	0.53	0.39	0.48

This retrospective study on intracranial pathologies showed that there was significant reduction in the mean FA and MD values for all intracranial lesions, except for metastases, compared to those in normal-appearing white matter (NAWM). This difference was statistically highly significant, with a p-value of 0.000.

5. CONCLUSION

This retrospective study on MRI DTI was performed to assess the FA and MD values of intracranial lesions. Compared to NAWM, the FA and MD values of these lesions were generally reduced, with the exception of metastases, which indicated a minor increase in both FA and MD values. FA and MD values have proven useful in the differential diagnosis of intracranial lesions. And therefore MR DTI sequence can be included as a part of the tailor made protocol in imaging all Intracranial lesions.

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Conflict of Interest

This research was carried out independently, without financial backing from any public, commercial, or non-profit funding sources. The authors further state that they have no conflicts of interest. The information from the study is maintained in strict confidentiality to safeguard patient rights, ensuring that no details are disclosed in publications or conference presentation

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Ethical Information

This study was approved by the institutional review board at SRM Medical College Hospital and Research Centre, SRMIST, Kattankulathur, Chennai (Ref No: CSP/21/MAY/94/347). The approval complies with ICMR guidelines for

biomedical research involving human subjects and adheres to clinical good practices. The checklist for student guides, required when submitting applications to the IEC, has been documented. Due to the study's nature, the requirement for obtaining informed consent from patients was waived.

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