

Role of Diffusion Tensor Imaging in Surgical Planning and Outcome Prediction in Glioma: A Prospective Study

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Abstract

Background: Diffusion Tensor Imaging (DTI) offers a unique, non-invasive approach to mapping white matter (WM) tracts and assessing their involvement in gliomas. This study explores the role of DTI in preoperative planning and predicting surgical outcomes in glioma patients.

Methods: A prospective, cross-sectional study was conducted on 72 patients with newly diagnosed gliomas. All underwent conventional MRI and DTI. WM tract involvement was classified as displaced, infiltrated, or disrupted. Surgical strategy and extent of resection were based on DTI findings. Postoperative outcomes were evaluated neurologically and radiologically.

Results: Among the 72 patients (mean age 44.35 years), 54.2% had low-grade and 45.8% had high-grade gliomas. DTI patterns were: displaced (54.2%), infiltrated (22.2%), and disrupted (23.6%). Gross total resection was achieved in 54.2%. Displaced patterns correlated with higher total resection and better postoperative outcomes. In contrast, disrupted patterns were associated with greater postoperative neurological deterioration.

Conclusion: DTI provides critical information on WM tract integrity and guides safer, more effective surgical approaches in glioma. Its integration into preoperative planning significantly influences the extent of resection and postoperative outcomes.

Keywords: Diffusion Tensor Imaging; Glioma, White Matter Tracts; Surgical Planning; Outcome Prediction.

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Introduction

Gliomas are the most prevalent primary intrinsic brain tumors, arising from glial cells that support and protect neurons. They often exhibit infiltrative growth along white matter tracts, making complete surgical resection challenging without harming eloquent brain regions^{1, 2}. Standard imaging modalities, such as contrast-enhanced MRI, help in anatomical localization but provide limited information about the functional organization of the brain, especially the integrity of white matter (WM) pathways^{3, 4}. Diffusion Tensor Imaging (DTI), an advanced magnetic resonance imaging technique, measures the directional diffusivity of water molecules and enables in vivo visualization of WM tracts⁵. Metrics such as Fractional Anisotropy (FA) and Mean Diffusivity (MD) provide quantitative insights into WM integrity⁶. DTI tractography reconstructs three-dimensional images of major tracts and reveals their displacement, infiltration, or disruption by adjacent gliomas⁷.

The relationship between gliomas and WM tracts as visualized by DTI can significantly impact surgical strategy⁸. Integrating DTI into neurosurgical planning improves the precision of tumor excision and minimizes

postoperative deficits^{9, 10}. This study aims to evaluate the use of DTI in preoperative assessment, surgical decision-making, and prediction of outcomes in glioma patients.

Materials and Methods

This prospective cross-sectional study was conducted at Apollo Hospital, Chennai, from September 2021 to January 2022. Seventy-two patients with newly diagnosed and untreated gliomas were enrolled. All underwent conventional MRI and DTI using a 3T Philips scanner with an 8-element phased-array sensitivity-encoding head coil. DTI was performed using a single-shot spin-echo echo-planar imaging pulse sequence with TR 3000ms, TE 94ms, slice thickness 2.5mm, no inter-slice gap, and b-value of 1000 s/mm². Regions of interest (ROIs) were placed to reconstruct major white matter tracts, including the corticospinal tract, arcuate fasciculus, and superior/inferior longitudinal fasciculi.

Tract involvement was categorized into three patterns: Displaced (tract with slightly reduced FA but abnormal orientation), Infiltrated (tract with reduced FA, not clearly visible), and Disrupted (tract with near-isotropic diffusion and not visible on DTI maps). Surgical planning



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incorporated DTI findings, and intraoperative techniques like awake craniotomy and neuro-monitoring were employed selectively.

Inclusion Criteria

- Newly diagnosed, untreated glioma
- Evaluated with conventional MRI and DTI
- Informed consent obtained.

Exclusion Criteria

- Non-glioma CNS tumors
- Lack of DTI evaluation
- Refusal to participate

Data Collection

After ethical committee approval, data were collected through history, examination, and imaging. Surgical decisions were based on the DTI tract pattern, and the extent of resection was assessed postoperatively. The outcome was evaluated with neurological examination and imaging.

Statistical Analysis

Data were analyzed using SPSS v20.0. Descriptive statistics were calculated, and Chi-square/Fisher's exact tests were applied to assess significance, with $p < 0.05$ considered statistically significant.

Illustrative case 1

A 35-year-old gentleman presented with complaints of headaches in the last year and progressive weakness on the left side, with left-sided UMN facial palsy for the past four months. MRI Brain (Fig. 1a) showed a well-defined FLAIR hyperintense, non-contrast-enhancing lesion in the right insular region (Fig 1b). FA image (Fig 1c) showed a reduced FA value, and Tractography (Fig. 1d) showed that right

corticospinal tract fibers are displaced in a pattern in relation to the tumor. Based on DTI, a surgical plan and corridor were planned preoperatively. The patient underwent awake craniotomy, and near-total excision of the tumor was achieved. Histopathology was reported as astrocytoma grade 2. Post-surgery, the limb weakness gradually improved.

Illustrative case 2:

A 38-year-old lady presented with seizures and behavioral disturbance for 6 months without neurological deficit. She underwent brain MRI with DTI, which showed an ill-defined FLAIR hyperintense lesion (Fig. 2a) and a minimal contrast-enhancing lesion (Fig. 2b) in the left temporal region. FA image (Fig. 2c) showed a reduced FA value in the left inferior fronto-temporal occipital fibers, and tractography (Fig. 2d) showed a feature-infiltrated pattern of DTI. Surgical planning was done based on DTI. She underwent awake craniotomy and near-total excision of the lesion. Histopathology was reported as astrocytoma grade 2. Post-surgery, she was symptomatically improved and had her antiepileptic medication reduced.

Illustrative case 3

A 60-year-old gentleman presented with progressive headaches and speech difficulties for the past 2 months. On examination, he had a motor speech deficit and grade 1 papilledema. He was evaluated with a brain MRI (Fig. 3a), which showed a FLAIR hyperintense, ill-defined lesion in the frontal region, and a contrast-enhanced T1 image (Fig. 3b) showed a peripheral ring-enhancing lesion with

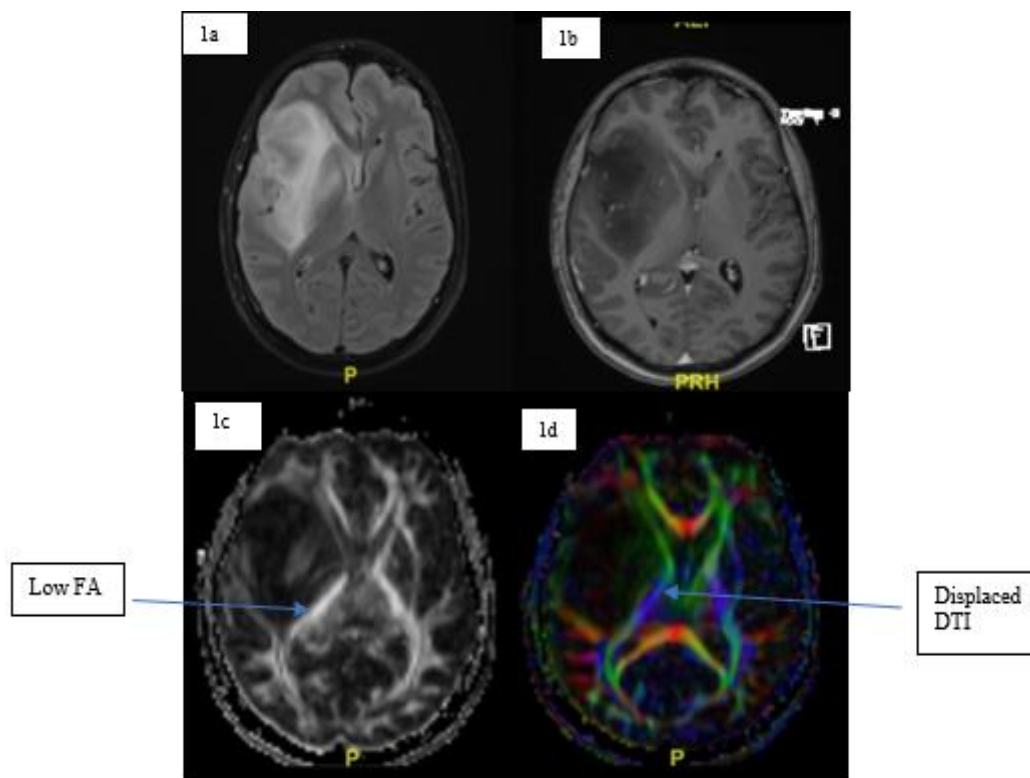


Figure 1. MRI and DTI tractography of a right insular glioma showing displacement of the right corticospinal tract. (a) FLAIR image showing a hyperintense lesion in the right insular region; (b) contrast-enhanced T1-weighted MRI; (c) fractional anisotropy (FA) image showing reduced FA; and (d) DTI tractography demonstrating displacement of the right corticospinal tract.

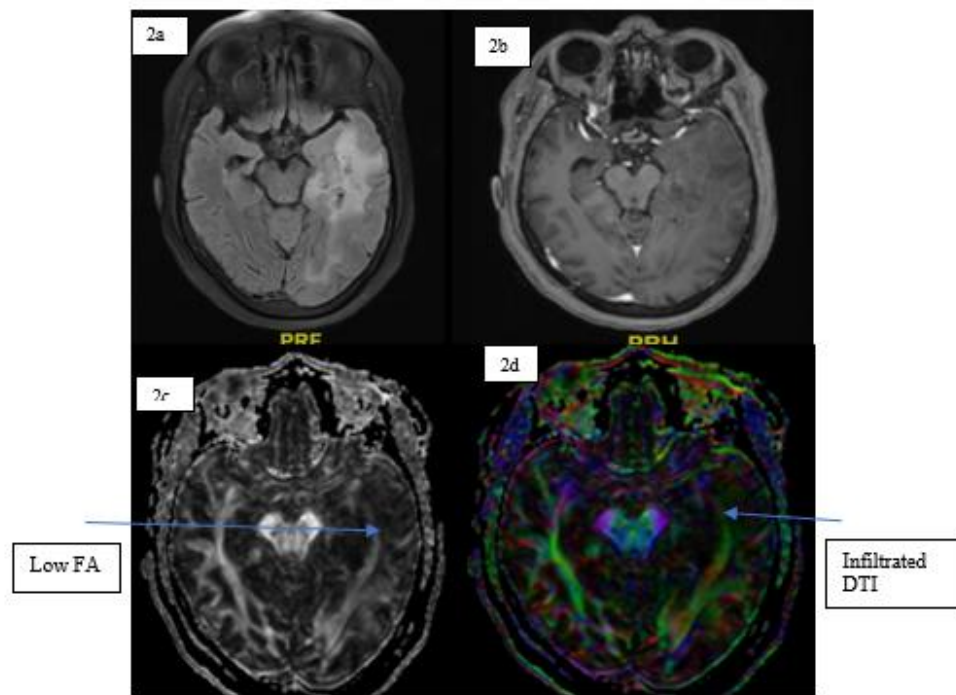


Figure 2. MRI and DTI tractography of a left temporal glioma showing an infiltrated white matter tract pattern. (a) FLAIR image showing an ill-defined hyperintense lesion in the left temporal region; (b) contrast-enhanced T1-weighted MRI; (c) FA image showing reduced FA; and (d) DTI tractography demonstrating an infiltrated tract pattern.

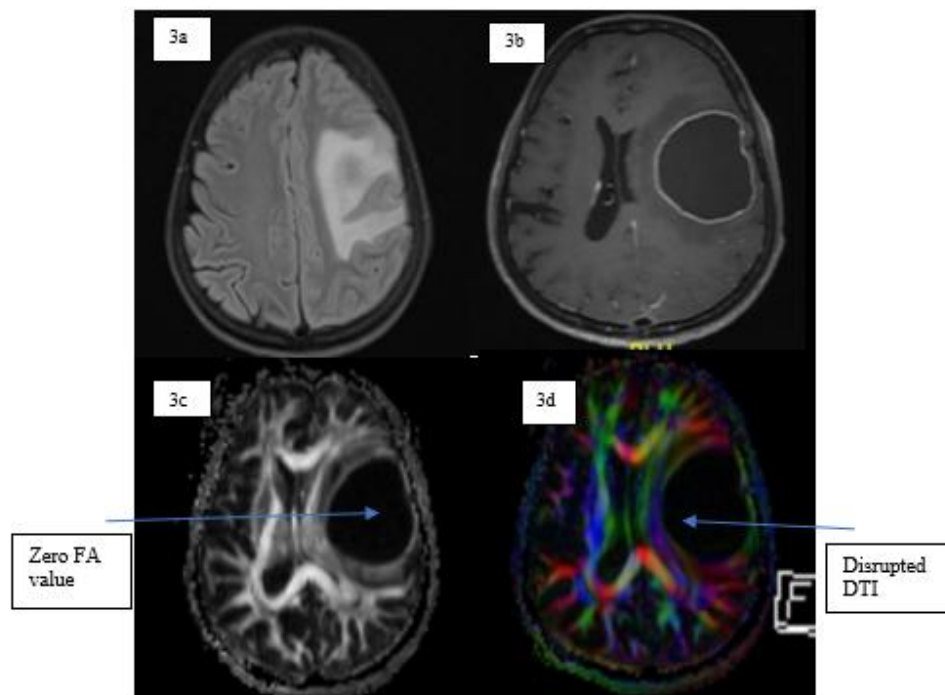


Figure 3. MRI and DTI tractography of a left frontal glioblastoma showing a disrupted white matter tract pattern. (a) FLAIR image showing an ill-defined frontal lesion; (b) contrast-enhanced T1-weighted MRI showing a peripheral ring-enhancing lesion with necrosis; (c) FA image showing absent/zero FA within the left arcuate fibers; and (d) DTI tractography demonstrating a disrupted tract pattern.

necrosis. FA image (Fig. 3c) showed zero FA value in left arcuate fibers, and tractography (Fig. 3d) showed a disrupted pattern of DTI. The patient underwent craniotomy and gross total excision of the lesion. Histopathology reported it as glioblastoma. Post-surgery, his speech deficit has persisted.

Results

The study included 72 patients with newly diagnosed gliomas, comprising 59 males (81.9%) and 13 females (18.1%), with a mean age of 44.35 years. Tumors were predominantly located in the frontal lobe (47.2%), followed by multilobar (29.2%), temporal (13.9%), parietal (4.6%), and insular region (4.2%). The tumor was located on the left

side in 58.3% and on the right side in 41.7% of cases. Histologically, 54.2% (n=39) were low-grade gliomas and 45.8% (n=33) were high-grade gliomas.

Based on DTI patterns, displaced tracts were observed in 54.2% (n=39), infiltrated tracts in 22.2% (n=16), and disrupted tracts in 23.6% (n=17). Gross total resection (GTR) was achieved in 54.2% (n=39) of patients, while the rest underwent subtotal resection. The displaced pattern showed the highest GTR rate (74.4%), compared with 41.2% in the disrupted and 18.8% in the infiltrated patterns ($p < 0.001$). Postoperative neurological outcomes varied by DTI pattern. In displaced tracts, 76.9% had no deterioration, 12.8% experienced decline, and 10.3% showed improvement. In infiltrated tracts, 62.5% had no deterioration, and 37.5% had a decline. In disrupted tracts, 47% had no deterioration, 53% experienced deterioration, and 5.8% showed improvement

Table 1. Patient demographics.

Variable	Category	Frequency	Percentage
Age	<30	8	11.1%
	30-40	21	29.2%
	40-50	22	30.6%
	>50	21	29.2%
Gender	Male	59	81.9%
	Female	13	18.1%
Tumor Side	Left	42	58.3%
	Right	30	41.7%
Tumor Location	Frontal	34	47.2%
	Temporal	10	13.9%
	Parietal	4	4.6%
	Insular	3	4.2%
	Multilobar	21	29.2%

Table 2. DTI pattern vs tumor grade.

DTI Pattern	Low Grade	High Grade	P-Value
Displaced	21 (53.8%)	18 (46.2%)	0.105
Infiltrated	8 (50%)	8 (50%)	
Disrupted	4 (23.6%)	13 (76.4%)	

*P-value < 0.05 statistically significant

Table 3. DTI pattern vs type of resection.

DTI Pattern	Subtotal Resection	Gross Total Resection	P-Value
Displaced	10 (25.6%)	29 (74.4%)	<0.001*
Infiltrated	13 (81.2%)	3 (18.8%)	
Disrupted	10 (58.8%)	7 (41.2%)	

*P-value < 0.05 statistically significant

($p=0.002$). High-grade gliomas were more likely to exhibit disrupted patterns, whereas low-grade gliomas were more

Table 4. DTI pattern vs postoperative outcome.

DTI Pattern	No Deterioration	Motor/Cognitive / Language Decline	Improvement	P-Value
Displaced	30 (76.9%)	5 (12.8%)	4 (10.3%)	0.002*
Infiltrated	10 (62.5%)	6 (37.5%)	0	
Disrupted	8 (47%)	9 (53%)	1 (5.8%)	

*P-value < 0.05 is statistically significant

likely to exhibit displaced or infiltrated patterns, although this trend did not reach statistical significance ($p = 0.105$).

Discussion

Our study reinforces the growing body of evidence supporting the utility of DTI in the surgical management of gliomas. The ability of DTI to delineate WM tracts and classify their relationship to gliomas as displaced, infiltrated, or disrupted is of critical value.

DTI tractography has been shown to predict surgical risks and guide neurosurgeons in planning approaches that minimize neurological deficits. Witwer et al. Classified tumor-tract interactions into the categories of displacement, infiltration, and disruption, establishing the foundation for intraoperative decision-making⁷. Our findings are consistent with this framework, with displaced tracts showing the highest rates of gross total resection and best neurological outcomes.

The association between DTI pattern and glioma grade also aligns with prior literature. Displacement is more commonly observed in low-grade gliomas (LGG), whereas infiltration and disruption are more typical of high-grade gliomas (HGG), reflecting their greater aggressiveness^{5, 11}. Ibrahim et al. found a significant association between tract disruption and malignancy, supporting our observation that disrupted fibers are more prevalent in HGG and correlate with worse outcomes¹².

The impact of tractography on surgical planning cannot be overstated. Studies by Bello et al. And Leclercq et al. Demonstrated that DTI-guided resections resulted in fewer functional impairments, particularly when used alongside intraoperative tools like awake craniotomy and neuromonitoring^{13, 14}. In our study, the adjunctive use of intraoperative monitoring tools in 16 cases was associated with significantly better outcomes ($p = 0.009$).

Furthermore, Cao et al. Emphasized the use of DTI in brainstem gliomas, highlighting its role in enhancing safety margins without compromising tumor resection¹⁵. Similarly, Dubey et al. Advocated for preoperative DTI to improve resection rates and reduce neurological complications¹⁶.

Despite its advantages, DTI has limitations. Image resolution, partial volume effects, and difficulty in interpreting tracts near edematous or necrotic tissue may hinder accuracy. Nonetheless, when combined with clinical judgment and intraoperative adjuncts, it offers substantial benefit.

Conclusion

Diffusion Tensor Imaging (DTI) is a valuable adjunct in glioma surgery, enabling precise visualization of white matter tract involvement. Our study highlights that DTI patterns that are displaced, infiltrated, or disrupted significantly influence the extent of tumor resection and postoperative neurological outcomes. Displaced tracts are associated with better surgical and functional results, while disrupted tracts often correlate with high-grade tumors and poorer prognosis. Incorporating DTI into preoperative

planning can thus enhance surgical safety, guide decision-making, and improve overall patient outcomes.

Acknowledgments

None.

Ethical consideration

The study was conducted in accordance with the guidelines of the university ethics committee and received approval from the Institutional Review Board (Reference No. 522-41102-191-222484). Written informed consent was obtained from all participants (aged >16 years) after they were fully informed about the study objectives and procedures, and confidentiality was ensured.

Competing Interests

The authors declare no conflict of interest.

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