Turk Neurosurg 36(1):99-107, 2026
DOI: 10.5137/1019-5149.JTN.48739-25.2

Original Investigation

Spine and Peripheral Nerves

Received: 11.03.2025
Accepted: 01.06.2025
Published Online: 16.01.2026

The Role of DTI and DTT in the Evaluation of Cervical Extramedullary Tumors

Zeynep FIRAT[1], Cumhur Kaan YALTIRIK[2], Aysegul GORMEZ[1], Osman Melih TOPCUOGLU[1], Gazanfer EKINCI[1], Ugur TURE[3]

[1]Yeditepe University Hospitals, Department of Radiology, Istanbul, Türkiye
[2]Maltepe University, School of Medicine, Department of Neurosurgery, Istanbul, Türkiye
[3]Yeditepe University Hospitals, Department of Neurosurgery, Istanbul, Türkiye

Corresponding author: Zeynep FIRAT ✉ zfirat@yeditepe.edu.tr

ABSTRACT

AIM: To evaluate the efficacy of diffusion tensor imaging (DTI) and diffusion tensor tractography (DTT) in establishing the relationship between cervical extramedullary tumors and the spinal cord with reference to, especially treatment planning, clinical outcome prediction and diagnostic accuracy.

MATERIAL and METHODS: This was a retrospective study conducted on 15 patients diagnosed with cervical extramedullary tumors, wherein each patient underwent standard 3.0-T magnetic resonance imaging, DTI, and DTT to evaluate microstructural changes and neural tract displacement. Fractional anisotropy (FA) values were examined, and the relationship of tractography results with clinical presentation and outcomes was evaluated.

RESULTS: FA values revealed disturbances in the microstructure, which exhibited marked changes in lesion areas compared with that of normal tissue and displaced spinal cord (DSC). The DTT of each patient revealed neural tract anomalies or deformities related to the degree of their clinical symptoms. Receiver operating characteristic curve analysis demonstrated the excellent diagnostic accuracy of FA in separating lesions from normal tissue (AUC = 0.880) and DSC (AUC = 0.840).

CONCLUSION: FA values could help particularly in detecting early myelopathic changes due to cervical cord displacement, which might be a critical indication for surgical decisions. This study supports the usage of DTI and DTT in evaluating cervical extramedullary lesions, surgical planning, and outcome prediction by exposing microstructural changes and lesion–tract relationships.

KEYWORDS: Cervical extramedullary tumors, Diffusion tensor imaging, Diffusion tensor tractography, Cervical spinal cord, Surgical planning

INTRODUCTION

The cervical spinal cord is a fundamental anatomical structure for neural signals where lesions can significantly affect function and quality of life. Magnetic resonance imaging (MRI) is a basic technique for the diagnosis and differentiation of lesions in the cervical spinal cord, helping in surgical planning and patient management (4). Diffusion tensor imaging (DTI) and diffusion tensor tractography (DTT) provide spinal imaging with a novel viewpoint and essential knowledge of the microstructural integrity of neural pathways (2,5-7). These two techniques are quite helpful in evaluating patients with different spinal diseases, including intramedullary and extramedullary tumors, vascular malformations, and traumatic spinal cord injury. They provide comprehensive information on the directionality and integrity of fiber tracts (11,13,16,22).

Zeynep FIRAT : 0000-0001-6810-6360
Cumhur Kaan YALTIRIK : 0000-0002-4312-5685
Aysegul GORMEZ : 0000-0001-5620-2881
Osman Melih TOPCUOGLU : 0000-0002-4008-3395
Gazanfer EKINCI : 0000-0002-1589-1833
Ugur TURE : 0000-0002-7449-6171

This work is licensed by “Creative Commons Attribution-NonCommercial-4.0 International (CC)”.

DTI and DTT can effectively detect changes in neural tracts and their surroundings. They can provide details on deviation, deformation, and disturbance, which would be vital for determining the degree of damage and organizing surgical treatments (3,8,19,21,22). Furthermore, there is ongoing research on the predictive power of these imaging techniques in deciding outcomes and guiding therapy development. Some studies have also demonstrated a correlation between DTT results and neurological examination findings (19,22). Despite these advances, it is necessary to investigate the application of DTI and DTT in the framework of cervical extramedullary lesions and their efficacy in this particular context. Accordingly, this study was conducted to explore the usefulness of DTI and DTT to address the knowledge gap in the relationship between cervical extramedullary tumors and the spinal cord. Moreover, by analyzing the impact, we attempted to examine in detail how cervical extramedullary tumors interact with the spinal cord, thus guiding treatment strategies, clinical outcomes, and surgical approach.

MATERIAL and METHODS

Ethical Considerations

This study was conducted according to the Declaration of Helsinki and approved by the Yeditepe University Ethical Committee (IRB Approval Number: 1344). Informed consent was obtained from each study participant.

Study Design and Patient Population

This retrospective study was conducted between January 2018 and May 2024 in a tertiary care center on 15 patients, including 8 men and 7 women, who were diagnosed with extramedullary cervical spine lesions. Patients were included, irrespective of whether they were advised for either conservative management or surgical intervention after confirming extramedullary cervical spine lesions. All patients underwent the cervical MRI protocol, which also included a focused DTI sequence for microstructural analysis and lesion evaluation. Exclusion criteria were incomplete or low-quality imaging data, intramedullary or other cervical lesion type, and previous cervical spine surgery.

Imaging Protocol

All participants underwent MRI on a 3.0-T system (GE Discovery MR750w, GE Healthcare, Waukesha, USA) with a 24-channel neck coil covering the C1–C7 levels. A T2-weighted fast spin-echo (FSE) sequence was performed with a TR of 3450 ms, a TE of 96.1 ms, and a matrix size of 416 × 288. The focused DTI sequence was acquired using a spin-echo echo-planar imaging (SE/EPI) technique with a TR of 6000 ms, a TE of 71.9 ms, and a matrix size of 128 × 34, applying diffusion weighting along 16 directions (b-values: 0 and 800 s/mm^2). Both sequences were acquired in the sagittal plane with a field of view (FOV) of 18 cm, a slice thickness of 3.0 mm, and 16 slices with no interslice gap.

Diffusion Tensor Tractography

A specialized workstation (GE, AWS Portal 3.2 Ext. 4.0) was used to generate fractional anisotropy (FA) maps and perform tractography analyses. Although the FA maps were generated automatically, regions of interest (ROIs) were manually placed on the normal-appearing spinal cord, above and below the lesion to initiate fiber tracking.

Data Analysis

Demographic and clinical data, including age, gender, and clinical presentation, were recorded. Imaging findings from conventional MRI, DTI metrics (FA values), and DTT results were analyzed. FA measurements were obtained using ROIs (10–30 mm in size) from the normal-appearing cervical spinal cord, the cervical spinal cord near the lesion, and directly over the lesion. Tractography results were analyzed to determine the relationship between lesions and the surrounding structures, which were categorized as normal, deviated, deformed, or interrupted fibers. The relationship between DTT results and clinical symptoms was evaluated to explore the potential impact of extramedullary lesions on the microstructure and function of the cervical spinal cord.

Statistical Analysis

Statistical analyses were conducted using the SPSS software (version 27, IBM Corp., Armonk, NY, USA). Skewness and kurtosis coefficients were calculated to determine whether the values for each continuous variable followed a normal distribution. Categorical variables were expressed as frequencies (n, %), and continuous variables were summarized using mean and standard deviation.

The Mann–Whitney U test was applied to compare continuous variables between two groups, whereas comparisons between more than two groups were performed using the Kruskal–Wallis test. Post hoc analysis to determine the groups that contributed to significant differences was performed using Dunnett's multiple comparison test. Within-group repeated measures were analyzed using the Friedman test, and subgroup repeated measures were analyzed using the Wilcoxon signed-rank test.

The diagnostic performance of FA scores in differentiating the presence of lesions was evaluated using receiver operating characteristic (ROC) curve analysis. The optimal FA cutoff was determined using the Youden index. The diagnostic performance of FA was expressed in terms of sensitivity, specificity, positive predictive value, negative predictive value, and accuracy. Categorical data were compared using Fisher's exact test. Results were considered statistically significant at $p<0.05$ (two-tailed) within a 95% confidence interval.

RESULTS

The mean age of the 15 participants was 48.73 ± 12.55 (range: 33–68) years, and there were 7 (47%) women and 8 (53%) men. The following tumor types were identified: meningioma in 6 patients (40%), schwannoma in 6 patients (40%), chordoma in 2 patients (13%), and osteoblastoma in 1 patient (6.7%). The mean tumor size was 34.80 ± 18.16 (range: 12–88) mm. Table I shows the detailed characteristics of the patients.

DTI Measurements and FA

The mean FA values for normal tissue, displaced spinal cord (DSC), and lesion areas were 0.54 ± 0.13, 0.51 ± 0.12, and 0.31 ± 0.16, respectively. The FA values showed a statistically significant difference based on the measurement region (χ^2 = 25.200; $p<0.001$). Subgroup analysis showed that FA values were significantly lower in the lesion area than in the normal tissue and DSC ($p<0.001$). However, the FA values were not statistically significantly different between normal tissue and DSC ($p>0.05$).

Patients classified as "normal" on DTI/DTT analysis exhibited no significant differences in FA values between normal tissue, DSC, and lesion areas ($p>0.05$). In contrast, patients classified as "deviation" showed a significant decrease in FA values from normal tissue to the lesion area (χ^2 = 20.667; $p<0.001$).

Table I: Patient/Lesion / MR Characteristics

Variables			**n (%)**
Patient			
	Age (years)	Mean ± SD (range)	48.73 ± 12.55 (33–68)
	Gender		
		Female	7 (46.7)
		Male	8 (53.3)
Lesion			
	Size (mm)	Mean ± SD (range)	34.80 ± 18.16 (12–88)
	Histological Type		
		Meningioma	6 (40)
		Schwannoma	6 (40)
		Others	3 (20)
	Localization		
		C1	1 (6.7)
		C1–2	4 (26.7)
		C1–4	1 (6.7)
		C2	3 (20)
		C2–3	2 (13.3)
		C2–5	1 (6.7)
		C6–7	2 (13.3)
		C7–T1	1 (6.7)
Magnetic Resonance Imaging Characteristics			
	T1 Signal Intensity		
		Hypointense	5 (33.3)
		Heterogeneous/Isointense	10 (66.7)
	T2 Signal Intensity		
		Hyperintense	8 (53.3)
		Heterogeneous/Isointense	7 (46.7)

For meningiomas and schwannomas, the FA values of lesions were significantly lower than those of normal tissue and DSC (χ^2 = 10.333–9.333; p<0.01). However, the FA values of DSC were higher for meningiomas and schwannomas than for other tumor types (Z = –2.028; p=0.043) (Table II).

FA Diagnostic Performance (ROC Analysis)

Although the ability of FA to differentiate normal tissue from DSC was poor and not statistically significant (AUC = 0.607; p=0.320), FA demonstrated excellent performance in distinguishing lesions from normal tissue (AUC = 0.880; 95% confidence interval (CI): 0.756–1; p<0.001) and lesions from DSC (AUC = 0.840; 95% CI: 0.693–0.987; p=0.002). The optimal cutoff points for distinguishing lesions from normal tissue and DSC were 0.39 and 0.36, respectively. The sensitivity, specificity, and accuracy of FA for distinguishing lesions from normal tissue were 93.3%, 80%, and 86.7%, respectively, and the respective values for distinguishing lesions from DSC were 100%, 60%, and 80% (Table III).

Patient Complaints and Symptoms

The most common symptom was neck pain in 9 patients (60%), followed by radiculopathy in 5 patients (33.3%), numbness in 4 patients (26.7%), and loss of balance in 1 patient (6.7%). Multiple symptoms were found in 6 patients (40%), and neurological findings were detected in 7 patients (46.7%). Symptoms were more common in patients classified as "deviation" on DTI/DTT analysis; however, these differences did not reach statistical significance (p>0.05). There was also no significant association between lesion type and symptom frequency (p>0.05) (Table IV).

Table II: Fractional Anisotropy (FA) Measurement Results

Variables	Normal (a)	DSC (b)	Lesion (c)	χ²	p-value	a vs b	a vs c	b vs c
All Patients	0.54 ± 0.13	0.51 ± 0.12	0.31 ± 0.16	25.200	**<0.001***	**0.053**	**<0.001***	**<0.001***
DTI/DTT Classification								
Normal	0.46 ± 0.17	0.48 ± 0.13	0.32 ± 0.13	4.667	0.097	-	-	-
Deviation	0.56 ± 0.12	0.52 ± 0.12	0.31 ± 0.17	20.667	**<0.001***	**0.023*****	**0.002****	**0.002****
Z/P-value	1.231/0.218	–0.362/0.717	–0.217/0.828					
Lesion Type								
Meningioma (1)	0.54 ± 0.15	0.49 ± 0.11	0.38 ± 0.17	10.333	**0.006****	0.249	**0.028*****	**0.027*****
Schwannoma (2)	0.61 ± 0.10	0.60 ± 0.06	0.29 ± 0.16	9.333	**0.009****	0.345	**0.028*****	**0.027*****
Others (3)	0.41 ± 0.03	0.37 ± 0.02	0.19 ± 0.03	6.000	0.050	-	-	-
K-Wχ²/P-value	5.057/0.080	7.592/**0.022*****	3.651/0.161					
Difference†		3 < 2						
Lesion Type								
Meningioma/ Schwannoma	0.57 ± 0.13	0.54 ± 0.10	0.34 ± 0.17	19.500	**<0.001***	0.136	**0.002****	**0.002****
Others	0.41 ± 0.03	0.37 ± 0.02	0.19 ± 0.03	6.000	0.050	-	-	-
Z/P-value	–2.028/**0.043*****	–2.318/**0.020*****	–1.664/0.096					

***DTI:** Diffusion tensor imaging, **DTT:** Diffusion tensor tractography*

Table III: Diagnostic Performance of FA (ROC Analysis Results)

Diagnostic Performance	Normal Tissue vs. DSC	Normal Tissue vs. Lesion	DSC vs. Lesion
AUC (95% CI)	0.607 (0.401–0.813)	0.880 (0.756–1)*	0.840 (0.693–0.987)**
Cut-off Point	0.65	0.39	0.36
Sensitivity	40%	93.3%	100%
Specificity	86.7%	80%	60%
Positive Predictive Value	75%	82.4%	71.4%
Negative Predictive Value	59.1%	92.3%	100%
Accuracy	63.3%	86.7%	80%

***DSC:** Displaced spinal cord.*

Table IV: Patient Complaints/Symptoms

Complaints/Symptoms	n	DTI/DTT Normal	Deviation	p-value (a)
Neck pain, n (%)	9	1 (33.3)	8 (66.7)	0.525
Radiculopathy, n (%)	5	0 (0)	5 (41.7)	0.505
Numbness, n (%)	4	2 (66.7)	2 (16.7)	0.154
Loss of equilibrium, n (%)	1	0 (0)	1 (8.3)	>0.999
Multiple symptoms, n (%)	6	0 (0)	6 (50)	0.229
Neurological findings, n (%)	7	2 (66.7)	5 (41.7)	0.569
Complaints/Symptoms	**n**	**Lesion Type Meningioma/ Schwannoma**	**Other**	**p-value (a)**
Neck pain, n (%)	9	7 (58.3)	2 (66.7)	>0.999
Radiculopathy, n (%)	5	4 (33.3)	1 (33.3)	>0.999
Numbness, n (%)	4	4 (33.3)	0 (0)	0.516
Loss of equilibrium, n (%)	1	0 (0)	1 (33.3)	0.200
Multiple symptoms, n (%)	6	5 (41.7)	1 (33.3)	>0.999
Neurological findings, n (%)	7	6 (50)	1 (33.3)	>0.999
DTI/DTT				**p-value**
Normal, n (%)	3	3 (25)	0 (0)	>0.999
Deviation, n (%)	12	9 (75)	3 (100)	

*p>0.05, Fisher's exact test.

DISCUSSION

The findings of this study emphasize the significance of DTI and DTT in the evaluation of cervical extramedullary lesions and indicate their possible impact on surgical planning and neurological outcomes. Consistent with previous research demonstrating the sensitivity of DTI in identifying minor pathological changes within the spinal cord, the variations in FA values observed in our study patients indicate the microstructural changes occurring near extramedullary lesions (4,7,13). The ability of DTI to visualize the displacement or deformation of neural tracts provides invaluable guidance for surgical planning, enabling the preservation of neural integrity and possibly improving postoperative outcomes (19,22).

DTI and DTT have been confirmed to be valuable tools in distinguishing between intramedullary and extramedullary spinal lesions (1). Furthermore, they provide functional insights that complement conventional MRI (12,15). The general pattern of extramedullary lesions typically displaces and compresses the spinal cord (14). Intramedullary lesions often infiltrate and disrupt spinal cord tracts (10). DTI metrics such as FA may predict damage to the axon, which remains relatively preserved in extramedullary tumors but is significantly reduced in intramedullary lesions (9). In extramedullary lesions, DTT revealed that intact white matter tracts were displaced, whereas in intramedullary lesions, these tracts were disrupted or interrupted. These findings are consistent with those of previous studies, which indicate that DTI and DTT provide valuable microstructural information that helps in clinical decision-making and accurately characterizing the lesions, particularly in the context of surgical planning and predicting neurological outcomes (12,20).

This study emphasizes that DTI and DTT can contribute to surgical planning by supporting the diagnosis and clinical findings. The significant reduction in FA values effectively identified compression and microstructural changes in neural pathways, playing a pivotal role in preserving neural integrity during surgery and improving postoperative neurological outcomes. The high diagnostic performance of FA in distinguishing cervical extramedullary tumors from normal tissue and DSC underscores its clinical applicability. Moreover, the differences in FA values between tumor types suggest that DTI could serve as a complementary tool for tumor characterization.

Our findings correlated with the clinical presentation of the patients. Patients with pronounced deviation and deformation of neural tracts often presented with more severe neurological symptoms, including motor weakness and sensory deficits.

Conversely, patients with less pronounced imaging changes tended to have milder or asymptomatic changes, suggesting that DTI and DTT findings have prognostic implications for neurological outcomes. Previous studies have demonstrated a correlation between DTI metrics and clinical symptoms, suggesting that these imaging modalities are biomarkers of the integrity and function of the spinal cord (19,22). In addition, the use of DTT in surgical planning, as demonstrated in our study subjects, reflects the potential of this technology to minimize surgical morbidity by guiding the surgeon to avoid critical neural structures (7,19).

Our findings demonstrate that cervical extramedullary tumors impact spinal cord tracts differently based on tumor type and location. Meningiomas caused variable displacement, ranging from minimal to significant (Figures 1–2), whereas cystic schwannoma resulted in complete tract displacement and

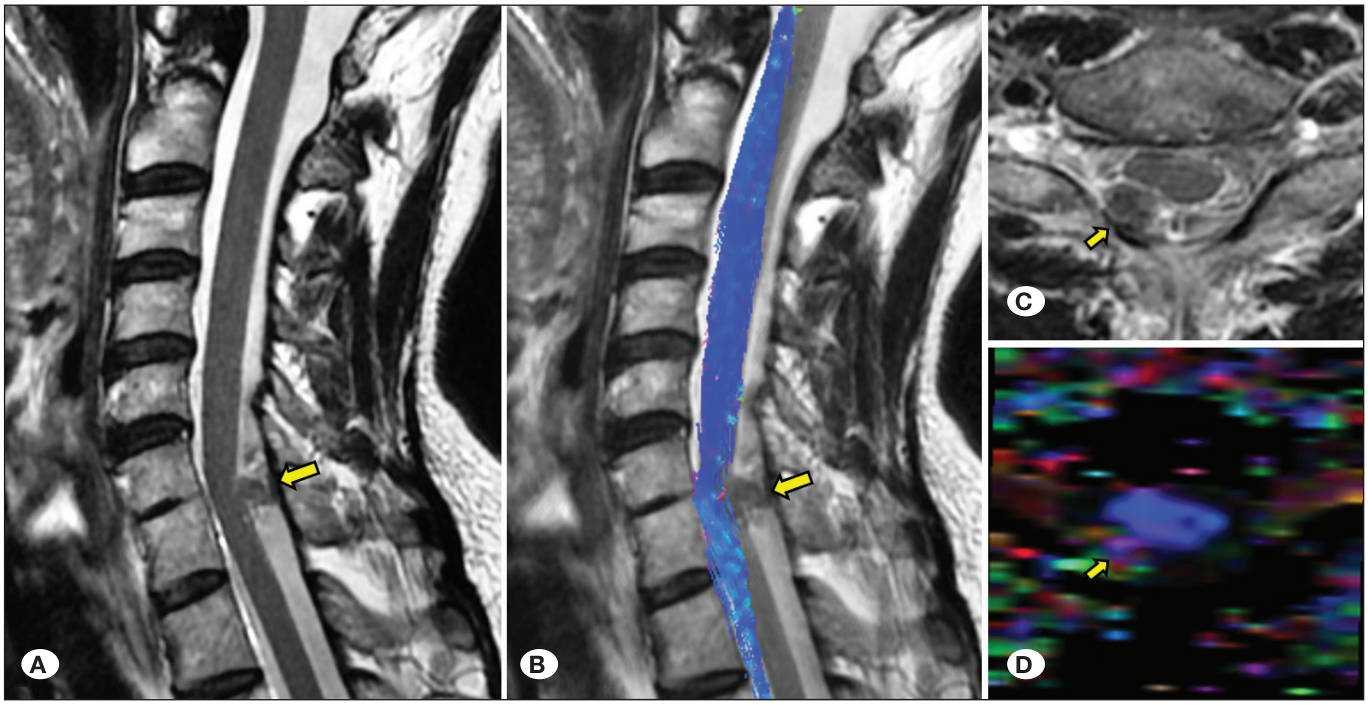

Figure 1: A 60-year-old woman with head and neck pain had a meningioma at C6–C7 (yellow arrows) with minimal displacement of the spinal cord tract. T2-weighted sagittal image **(A)**, tracts superimposed on a T2-weighted sagittal image **(B)**, a T2-weighted fat-saturated axial image **(C)**, and a color-coded FA map **(D)**.

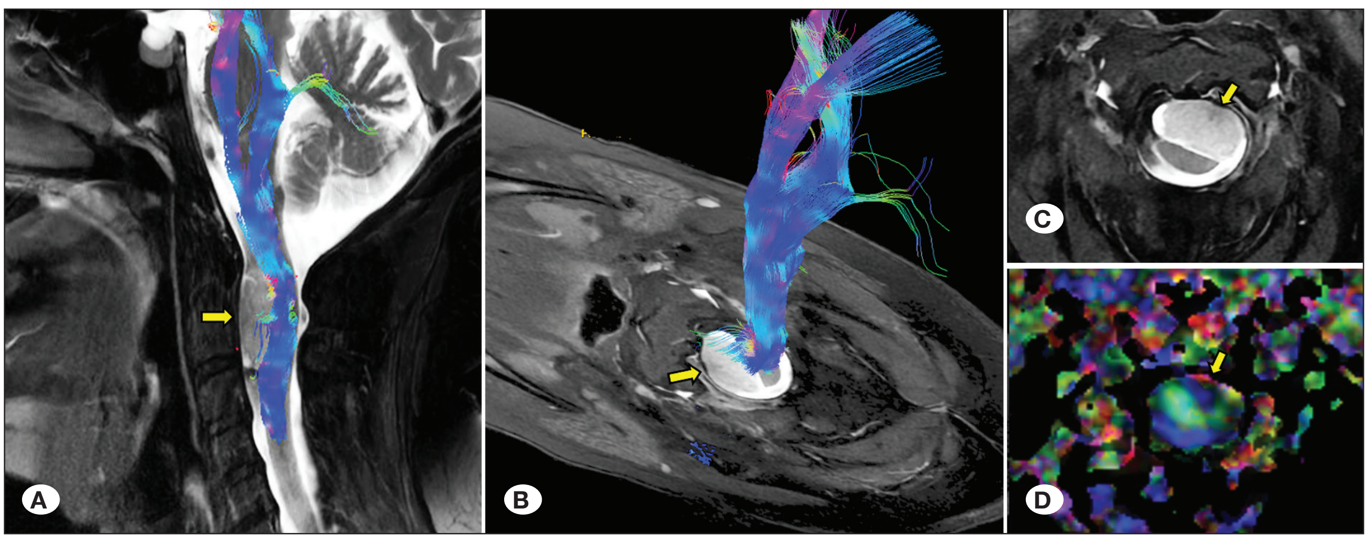

Figure 2: A 61-year-old woman with numbness in her extremities had a meningioma at C1–C2 (yellow arrows) causing displacement of spinal cord tracts. T2-weighted sagittal fat-saturated image **(A)**, T2-weighted axial fat-saturated image with cervical cord tracts **(B)**, T2-weighted axial fat-saturated image **(C)**, and color-coded FA map **(D)**.

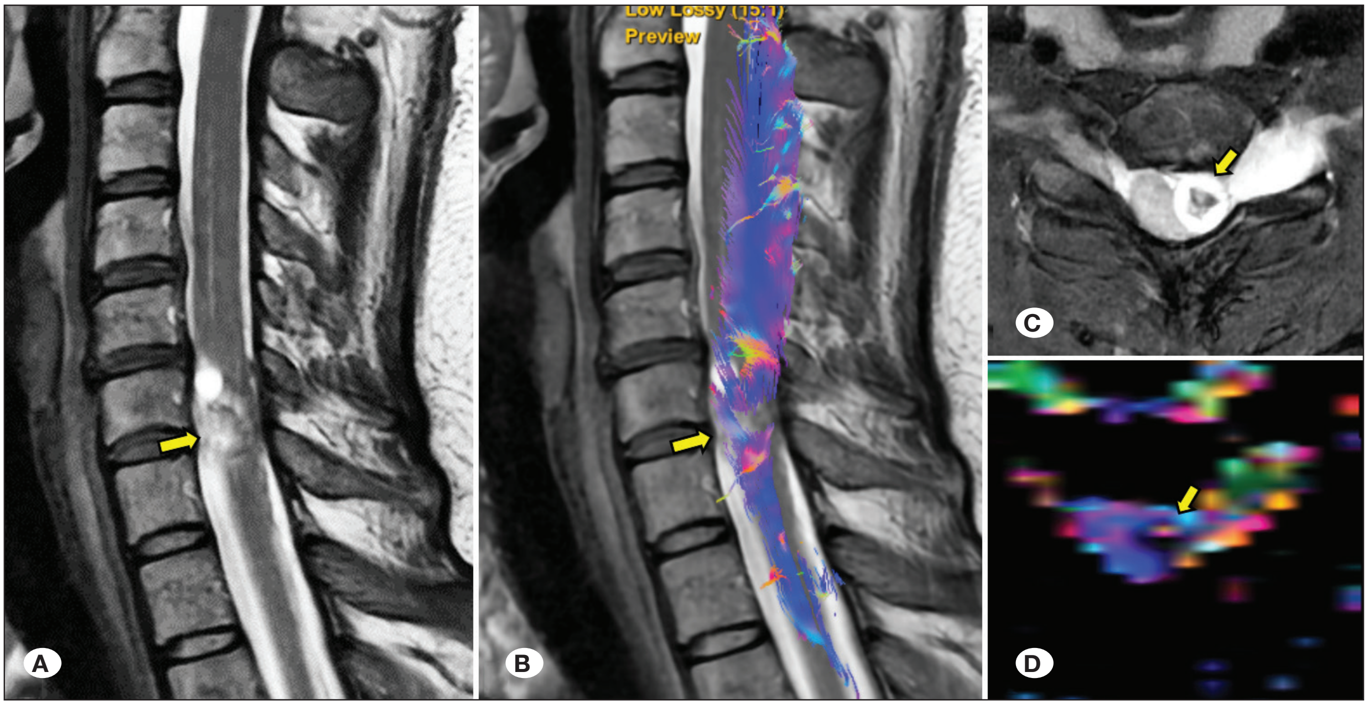

Figure 3: A 35-year-old woman with arm pain and numbness of the fingers showed a schwannoma with a cystic component at C6–C7 (yellow arrows) causing complete displacement of the spinal cord tract. T2-weighted sagittal image **(A)**, tracts superimposed on a T2-weighted sagittal image **(B)**, a T2-weighted fat-saturated axial image **(C)**, and a color-coded FA map **(D)**.

severe symptoms (Figure 3). These results emphasize the significance of DTI and DTT in correlating neural compression patterns with clinical presentation.

Although our study demonstrates the innovative and valuable role of DTI and DTT in preserving neural structures, technical challenges, such as motion artifacts, inhomogeneity, and the need for specialized expertise in analysis, limit generalizability (17). Moreover, the lack of a statistically significant relationship between clinical symptoms and DTI/DTT findings emphasizes the need for prospective studies with larger cohorts.

The limitations of our study include its retrospective design and the small sample size. Technical issues, including motion artifacts and the requirement for specialist analysis tools, may also limit the clinical adoption of these techniques (4,22). Nonetheless, their ability to advance knowledge and outcomes in spinal cord pathology warrants further prospective studies with larger cohorts (18).

Finally, the contribution of FA to the determination of microstructural changes may be important for decision-making regarding treatment or surgical approach. By revealing the microstructural changes and lesion–tract relationships, our study supports the use of DTI and DTT in evaluating cervical extramedullary lesions for surgical planning and outcome prediction.

CONCLUSION

Although DTI and DTT are generally applied in the evaluation of intra-axial brain tumors or intramedullary cervical tumors, they can provide valuable input in some cases of extramedullary cervical tumors, especially if the lesion causes displacement or compression of vital white matter tracts, and can assist in treatment and surgical planning. This study emphasizes the important role and clinical utility of DTI and DTT in the evaluation of extramedullary cervical tumors. The contribution of FA to the determination of microstructural changes may contribute to the early diagnosis of myelopathy findings, which may be a critical indicator for surgical decision-making.

Differences in the type, location, and size of cervical extramedullary tumors can provide information regarding the orientation of the tracts, the degree of spinal cord compression, and the associated clinical picture. Although larger scale studies are required to increase the reliability and clinical applicability of DTI and DTT in the evaluation of extramedullary cervical tumors, our findings may provide important contributions for understanding the effects of DTI and DTT on neural pathways in distinguishing extramedullary from intramedullary tumors and predicting neurological outcomes.

ACKNOWLEDGEMENTS

The authors would like to thank the patients and clinical staff for their participation and support throughout the study.

Declarations

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Availability of data and materials: The datasets generated and/or analyzed during the current study are available from the corresponding author by reasonable request.

Disclosure: The authors declare no competing interests.

AUTHORSHIP CONTRIBUTION

Study conception and design: ZF

Data collection: ZF, CKY, AG

Analysis and interpretation of results: ZF, CKY

Draft manuscript preparation: ZF, CKY, OMT

Critical revision of the article: GE, UT

Other (study supervision, fundings, materials, etc...): GE, UT

All authors (ZF, CKY, AG, OMT, GE, UT) reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Beall DP, Googe DJ, Emery RL, Thompson DB, Campbell SE, Ly JQ, DeLone D, Smirniotopoulos J, Lisanti C, Currie TJ: Extramedullary intradural spinal tumors: A pictorial review. Curr Probl Diagn Radiol 36:185-198, 2007. https://doi.org/10.1067/j.cpradiol.2006.12.002
2. Calabrese E, Adil SM, Cofer G, Perone CS, Cohen-Adad J, Lad SP, Johnson GA: Postmortem diffusion MRI of the entire human spinal cord at microscopic resolution. Neuroimage Clin 18:963-971, 2018. https://doi.org/10.1016/j.nicl.2018.03.029
3. Choudhri AF, Whitehead MT, Klimo P, Jr., Montgomery BK, Boop FA: Diffusion tensor imaging to guide surgical planning in intramedullary spinal cord tumors in children. Neuroradiology 56:169-174, 2014. https://doi.org/10.1007/s00234-013-1316-9
4. Costanzo R, Brunasso L, Paolini F, Benigno UE, Porzio M, Giammalva GR, Gerardi RM, Umana GE, di Bonaventura R, Sturiale CL, Visocchi M, Iacopino DG, Maugeri R: Spinal tractography as a potential prognostic tool in spinal cord injury: A systematic review. World Neurosurg 164:25-32, 2022. https://doi.org/10.1016/j.wneu.2022.04.103
5. Dauleac C, Frindel C, Pelissou-Guyotat I, Nicolas C, Yeh FC, Fernandez-Miranda J, Cotton F, Jacquesson T: Full cervical cord tractography: A new method for clinical use. Front Neuroanat 16:993464, 2022. https://doi.org/10.3389/fnana.2022.993464
6. D'Souza MM, Choudhary A, Poonia M, Kumar P, Khushu S: Diffusion tensor MR imaging in spinal cord injury. Injury 48:880-884, 2017. https://doi.org/10.1016/j.injury.2017.02.016
7. Ducreux D, Fillard P, Facon D, Ozanne A, Lepeintre JF, Renoux J, Tadie M, Lasjaunias P: Diffusion tensor magnetic resonance imaging and fiber tracking in spinal cord lesions: Current and future indications. Neuroimaging Clin N Am 17:137-147, 2007. https://doi.org/10.1016/j.nic.2006.11.005
8. Egger K, Hohenhaus M, Van Velthoven V, Heil S, Urbach H: Spinal diffusion tensor tractography for differentiation of intramedullary tumor-suspected lesions. Eur J Radiol 85:2275-2280, 2016. https://doi.org/10.1016/j.ejrad.2016.10.018
9. Firat Z, Topcuoglu OM, Yaltirik CK, Gormez A, Ekinci G, Ture U: Can qualitative cervical tractography predict clinical findings as effectively as it aids surgical planning today? Turk Neurosurg 34:1066-1072, 2024. https://doi.org/10.5137/1019-5149.JTN.46234-24.1
10. Hohenhaus M, Merz Y, Klingler JH, Scholz C, Hubbe U, Beck J, Wolf K, Egger K, Reisert M, Kremers N: Diffusion tensor imaging in unclear intramedullary tumor-suspected lesions allows separating tumors from inflammation. Spinal Cord 60:655-663, 2022. https://doi.org/10.1038/s41393-021-00741-2
11. Krisa L, Middleton DM, Saksena S, Faro SH, Leiby BE, Mohamed FB, Mulcahey MJ: Clinical utility of diffusion tensor imaging as a biomarker to identify microstructural changes in pediatric spinal cord injury. Top Spinal Cord Inj Rehabil 28:1-12, 2022. https://doi.org/10.46292/sci21-00048
12. Li DC, Malcolm JG, Rindler RS, Baum GR, Rao A, Khurpad SN, Ahmad FU: The role of diffusion tensor imaging in spinal pathology: A review. Neurol India 65:982-992, 2017. https://doi.org/10.4103/neuroindia.NI_198_17
13. Liang KN, Feng PY, Feng XR, Cheng H: Diffusion tensor imaging and fiber tractography reveal significant microstructural changes of cervical nerve roots in patients with cervical spondylotic radiculopathy. World Neurosurg 126:e57-e64, 2019. https://doi.org/10.1016/j.wneu.2019.01.154
14. Liu X, Tian W, Chen H, LoStracco TA, Zhang J, Li MY, Germin B, Wang HZ: Advanced neuroimaging in the evaluation of spinal cord tumors and tumor mimics: Diffusion tensor and perfusion-weighted imaging. Semin Ultrasound CT MR 38:163-175, 2017. https://doi.org/10.1053/j.sult.2016.07.006
15. Ottenhausen M, Ntoulias G, Bodhinayake I, Ruppert FH, Schreiber S, Forschler A, Boockvar JA, Jodicke A: Intradural spinal tumors in adults-update on management and outcome. Neurosurg Rev 42:371-388, 2019. https://doi.org/10.1007/s10143-018-0957-x
16. Rindler RS, Chokshi FH, Malcolm JG, Eshraghi SR, Mossa-Basha M, Chu JK, Kurpad SN, Ahmad FU: Spinal diffusion tensor imaging in evaluation of preoperative and postoperative severity of cervical spondylotic myelopathy: Systematic review of literature. World Neurosurg 99:150-158, 2017. https://doi.org/10.1016/j.wneu.2016.11.141
17. Rutman AM, Peterson DJ, Cohen WA, Mossa-Basha M: Diffusion tensor imaging of the spinal cord: Clinical value, investigational applications, and technical limitations. Curr Probl Diagn Radiol 47:257-269, 2018. https://doi.org/10.1067/j.cpradiol.2017.07.005
18. Scullen T, Milburn J, Aria K, Mathkour M, Tubbs RS, Kalyvas J: The use of diffusion tensor imaging in spinal pathology: A comprehensive literature review. Eur Spine J 33:3303-3314, 2024. https://doi.org/10.1007/s00586-024-08231-8
19. Shabani S, Kaushal M, Budde M, Kurpad SN: Correlation of magnetic resonance diffusion tensor imaging parameters with American Spinal Injury Association score for prognostication and long-term outcomes. Neurosurg Focus 46:E2, 2019. https://doi.org/10.3171/2018.12.FOCUS18595
20. Wang J, Huang J, Cui B, Yang H, Tian D, Ma J, Duan W, Dong H, Chen Z, Lu J: Diffusion tensor imaging identifies cervical spondylosis, myelitis, and spinal cord tumors. Diagnostics 14:1225, 2024. https://doi.org/10.3390/diagnostics14121225

21. Zaninovich OA, Avila MJ, Kay M, Becker JL, Hurlbert RJ, Martirosyan NL: The role of diffusion tensor imaging in the diagnosis, prognosis, and assessment of recovery and treatment of spinal cord injury: A systematic review. Neurosurg Focus 46:E7, 2019. https://doi.org/10.3171/2019.1.FOCUS18591
22. Zhu F, Liu Y, Zeng L, Wang Y, Kong X, Yao S, Chen K, Jing X, Yang L, Guo X: Evaluating the severity and prognosis of acute traumatic cervical spinal cord injury: A novel classification using diffusion tensor imaging and diffusion tensor tractography. Spine 46:687-694, 2021. https://doi.org/10.1097/BRS.0000000000003923