Turk Neurosurg 34(6):1066-1072, 2024

Original Investigation

DOI: 10.5137/1019-5149.JTN.46234-24.1

Received: 02.01.2024
Accepted: 13.03.2024

Published Online: 23.10.2024

Can Qualitative Cervical Tractography Predict Clinical Findings as Effectively as It Aids Surgical Planning Today?

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ABSTRACT

AIM: To investigate cervical spinal tractography (CST) and diffusion tensor imaging findings in patients with intramedullary cervical spinal cord (CSC) tumors and to evaluate the association between qualitative diffusion tensor tractography (DTT) findings and neurological examination findings (NEF).

MATERIAL and METHODS: Neuroradiology case records were retrospectively evaluated to identify patients with intramedullary CSC tumors who underwent cervical spinal DTT. Conventional magnetic resonance imaging (MRI) and DTT were performed using a 3.0-T MRI system. Demographic data, CST and clinical findings, fractional anisotropy (FA), and apparent diffusion coefficient (ADC) were recorded. The sensitivity, specificity, and positive and negative predictive values (PPV and NPV, respectively) were calculated.

RESULTS: This study enrolled 31 patients (16 women and 15 men) with a mean age of 35.2 ± 15.6 years (range: 1–70 years). The mean FA and ADC were 0.34 ± 0.45 and 1.88 ± 0.89, respectively. Physical examination revealed hemihypesthesia (19.3%), hemiparesis (16.1%), and quadriparesis (3.2%). Completely normal neurological findings were observed in 61.3% of the patients. DTT revealed deviation (n=15), deformation (n=11), and interruption (n=5) of the fibers. No significant relationship was observed between NEF and DTT findings (p=0.127). The sensitivity, specificity, PPV, and NPV of DTT for CSC tracts were 100%, 0%, 38.7%, and 0%, respectively.

CONCLUSION: Although qualitative DTT of the CSC might be useful for planning and preservation of the fiber tracts during intramedullary tumor surgery, it did not exhibit significant association with clinical findings in this study. Qualitative DTT of CSC in patients with intramedullary tumors may not correlate well with NEF.

KEYWORDS: Cervical spinal cord, Diffusion tensor imaging, Diffusion tensor tractography, Intramedullary tumors, Magnetic resonance, Tumors

ABBREVIATIONS: CST: Cervical spinal tractography, **DTI:** Diffusion tensor imaging, **CS:** Cervical spinal cord, **DTT:** Diffusion tensor tractography, **NEF:** Neurological examination findings, **FA:** Fractional anisotropy, **ADC:** Apparent diffusion coefficient, **MRI:** magnetic resonance imaging, **PPV:** Positive predictive value, **NPV:** Negative predictive value

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INTRODUCTION

Magnetic resonance imaging (MRI) is a fundamental and imperative imaging modality for detecting pathological signal changes, discriminating different lesions from each other, and surgical planning in the cervical spinal cord (CSC) (3). Moreover, diffusion tensor imaging (DTI) and diffusion tensor tractography (DTT) add important key findings and details through fractional anisotropy (FA), apparent diffusion coefficient (ADC) maps, and fiber tractography (6). Patients with intramedullary and extramedullary CSC tumors, vascular malformations, acute CSC injury, and external compression from cervical spondylosis can be evaluated by DTI and DTT (11,23). Previous studies have demonstrated that fiber tract alterations in the descending and ascending pathways as deviation, deformation, and interruption could be demonstrated by qualitative DTT (15,23). Furthermore, neurological examination along with the prognosis and outcome of CSC injuries might be predicted by DTT (15,23).

In this study, we aimed to investigate cervical spinal DTT and DTI findings in patients with CSC tumors and evaluate whether a significant association existed between qualitative DTT findings and neurological examination findings (NEF).

MATERIAL and METHODS

Patient Population

This retrospective study was approved by the Institutional Review Board (Yeditepe University Ethical Committee, No: 1344), and informed consent was obtained. Neuroradiology case records from a single center were retrospectively investigated between October 2017 and June 2022 to identify patients with intramedullary CSC lesions and DTI & DTT images. Patients with intramedullary CSC lesions without DTT images and those insufficient DTT image quality limiting tractography evaluation were excluded from the further evaluation. Detailed neurological examination was performed for all patients by a neurosurgeon with 30 years of experience.

MRI, DTI, and DTT techniques

Conventional MR sequences and DTI and DTT findings were obtained on a 3.0-T MRI system (GE Discovery MR750w, GE Healthcare, Waukesha, USA) equipped with a 24 channel neck coil. Patients were placed in the supine position, and their legs were supported by a cushion. The scanning field included C1–C7 level. T2 FSE (fast spin echo) sequence (TR: 3450 ms, TE: 96.1 ms, matrix: 416 × 288, FOV: 18 cm, slice thickness: 3.0 mm, gap: 0 mm, number of slices: 16) and focus DTI (SE/EPI: spin-echo echo-planar imaging) sequence, specifically designed for CSC imaging (TR: 6000 ms, TE: 71.9 ms, matrix: 128 × 34, FOV: 18 cm, slice thickness: 3 mm, gap: 0 mm, nex: 4, scanning time: 6.54, number of slices: 16, number of directions: 16, b = 0 and b = 800 <s/mm^2), were performed on the sagittal plane. T2 MERGE sequence (TR: 719, TE: 13.3, FOV: 15 × 15 mm, slice thickness: 4.0 mm, gap: 0.3 mm, matrix: 256 × 192) and T2 3D Cube sequence (TR: 1400, TE: 88.3, FA: 90, FOV: 17 × 17 mm, slice thickness: 1.4 mm, gap: –0.7 mm, matrix: 288 × 224) were performed on the axial plane.

Data analysis

All data were transferred to the locally available Workstation (GE, AWS Portal 3.2 Ext. 4.0) for generating FA and ADC maps and for tractography analyses. For the lesion, FA and ADC evaluations were performed on the solid component of the lesion or on the homogeneous enhancement region. For normalization, measurements were made from the area of the spinal cord that was considered normal. Cervical cord tractography was performed for demonstrating the ascending and descending pathways by placing ROIs (5–10 mm in diameter) on the normal part of the spinal cord on the axial plane. The association of the lesion with the pathways was evaluated as normal, deviated, deformed, or interrupted (10,18).

Statistical Analysis

Mean, standard deviation, and range were evaluated for all demographic data. Fisher's exact test, independent samples t-test, or Mann–Whitney U-test were used for categorical and continuous variables. The correlation between NEF and DTT findings, which were grouped as normal, deviated, deformed, and interrupted, was analyzed using the Spearman correlation coefficient test. The sensitivity, specificity, and positive and negative predictive values (PPV and NPV, respectively) of qualitative DTT were calculated, with physical examination findings considered the gold standard. All statistical analyses were conducted using commercially available software (version 20.0, IBM SPSS Statistics, IBM Corp.), and $p<0.05$ was considered statistically significant.

RESULTS

This study enrolled 31 patients (16 women and 15 men) with a mean age of 35.2 ± 15.6 years (range: 1–70 years). The pathologies of the patients are summarized in Table I. The mean FA and ADC were 0.34 ± 0.45 and 1.88 ± 0.89, respectively. Detailed physical examination revealed hemiparesis (16.1%), hemihypoeshtesia (19.3%), and quadriparesis (3.2%). Completely normal neurological findings were observed in 61.3% of the patients (n=19). DTT revealed deviation (n=15), deformation (n=11), and interruption (n=5) of the fibers. No patient had normal tractography findings. The characteristics of each case are shown in Table II. Representative cases are shown in Figures 1–3. Abnormal tractography findings were detected in 19 patients who had normal neurological findings. Three patients with interrupted fiber tracts showed normal physical examination findings. No significant relationship was observed between clinical examination and DTT findings (p=0.127). The sensitivity, specificity, PPV, and NPV of DTT for CSC tracts were 100%, 0%, 38.7%, and 0%, respectively.

DISCUSSION

DTT and DTI are relatively new imaging modalities in the field of magnetic resonance technology. DTT provides pivotal anatomical information for preoperative surgical planning concerning the entry zone and surgical trajectory in the brain stem and eloquent region lesions (14,17,19). Nevertheless, despite its increasing use in acute spinal cord injuries, spondylotic

Table I: Cervical Spinal Cord Tumors, Fiber Tract Changes on DTT and Neurological Examination Findings

Histopathological Diagnosis (n=31)	Diffusion Tensor Tractography Findings			Neurological Examination	
	Deviated (n=15)	Deformed (n=11)	Interrupted (n=5)	Normal (n=19)	Abnormal (n=12)
Ependymoma (n=13)	7	4	2	8	5
Cavernoma (n=7)	4	1	2	2	5
Astrocytoma (n=9)	3	5	1	8	1
Hemangioblastoma (n=1)	-	1	-	1	-
Hemangioma (n=1)	1	-	-	-	1

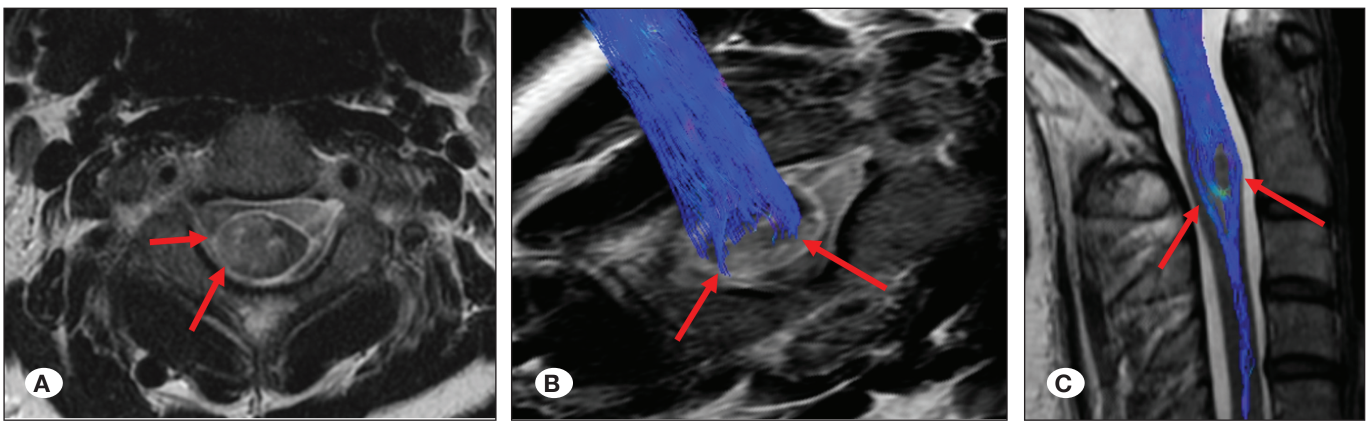

Figure 1: Axial plane T2-weighted MR image **(A)** reveals pathologically proven cervical spinal cavernous malformation (arrows) in a 24-year-old female patient with normal neurological examination. Axial and sagittal plane diffusion tensor tractography images **(B and C)** demonstrate anterior and posterior deviation (arrows) of the ascending and descending pathways.

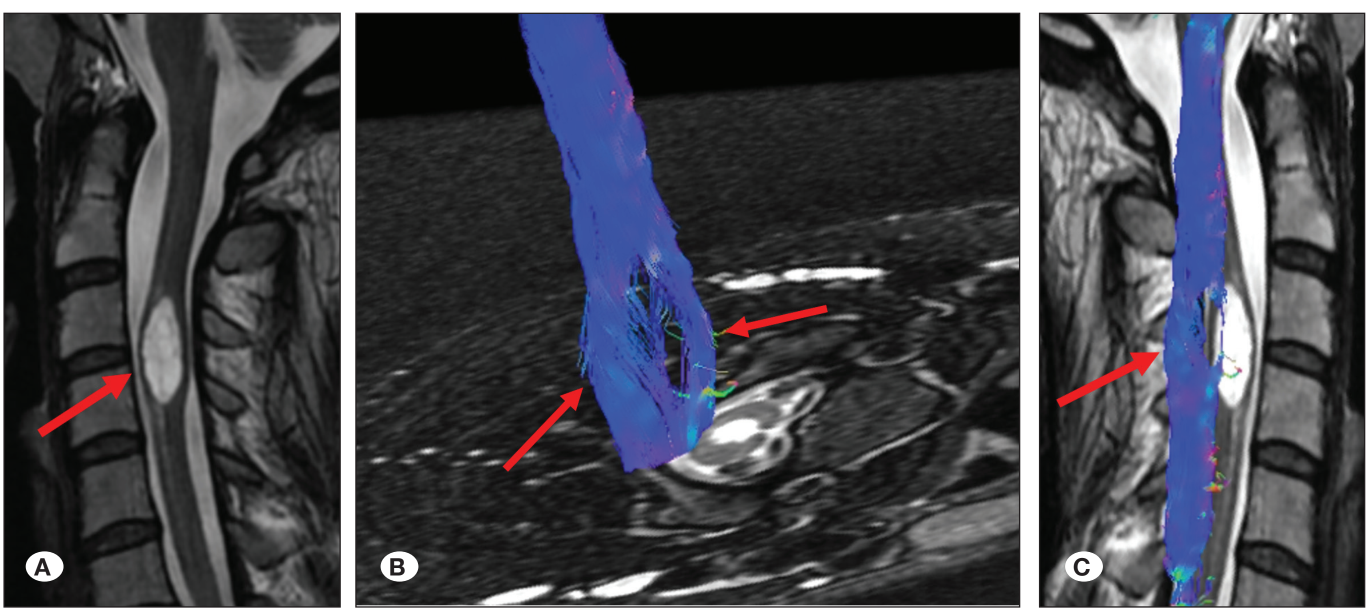

Figure 2: Sagittal plane T2-weighted MR image **(A)** reveals pathologically proven cervical spinal ependymoma (arrow) in a 29-year-old female patient with normal neurological examination. Axial and sagittal plane diffusion tensor tractography images **(B and C)** reveal deviation (arrows) of the fiber tracts due to the expansile mass lesion.

myelopathy, and intramedullary and extramedullary spinal cord tumors, the exact clinical implications of DTT are not well established and remain controversial (4,7,13,23). The present study demonstrated that although 61.3% of the patients had normal neurological examination results, no patient had normal fiber tractography findings. In other words, all patients had abnormal tracts on DTT; however, these findings did not correlate with the physical examination results. Therefore, the PPV remained low in this case series.

Table II: Cervical Spinal Cord Tumors, Diffusion Tensor Tractography and Neurological Examination Characteristics of Each Patient

Case	Sex	Pathology	Neurological Examination	DTT
1	M	Ependymoma	Hemihypoesthesia	Deviated
2	F	Ependymoma	Normal	Deformed
3	F	Ependymoma	Normal	Deformed
4	M	Ependymoma	Normal	Deviated
5	M	Ependymoma	Normal	Interrupted
6	F	Ependymoma	Quadriparesis	Interrupted
7	M	Ependymoma	Normal	Deviated
8	F	Ependymoma	Normal	Deviated
9	M	Ependymoma	Hemiparesis	Deformed
10	M	Ependymoma	Normal	Deviated
11	M	Ependymoma	Hemihypoesthesia	Deviated
12	F	Ependymoma	Normal	Deviated
13	M	Ependymoma	Hemiparesis	Deformed
14	M	Cavernoma	Hemiparesis	Interrupted
15	F	Cavernoma	Hemiparesis	Deviated
16	F	Cavernoma	Normal	Interrupted
17	F	Cavernoma	Normal	Deformed
18	F	Cavernoma	Hemihypoesthesia	Deviated
19	M	Cavernoma	Hemiparesis	Deviated
20	F	Cavernoma	Hemihypoesthesia	Deviated
21	F	Astrocytoma	Normal	Deviated
22	F	Astrocytoma	Hemihypoesthesia	Deformed
23	F	Astrocytoma	Normal	Interrupted
24	F	Astrocytoma	Normal	Deformed
25	M	Astrocytoma	Normal	Deformed
26	M	Astrocytoma	Normal	Deviated
27	M	Astrocytoma	Normal	Deformed
28	F	Astrocytoma	Normal	Deformed
29	M	Astrocytoma	Normal	Deviated
30	M	Hemangioblastoma	Normal	Deformed
31	F	Hemangioma	Hemihypoesthesia	Deviated

***M:** Male, **F:** female, **DTT:** diffusion tensor tractography.*

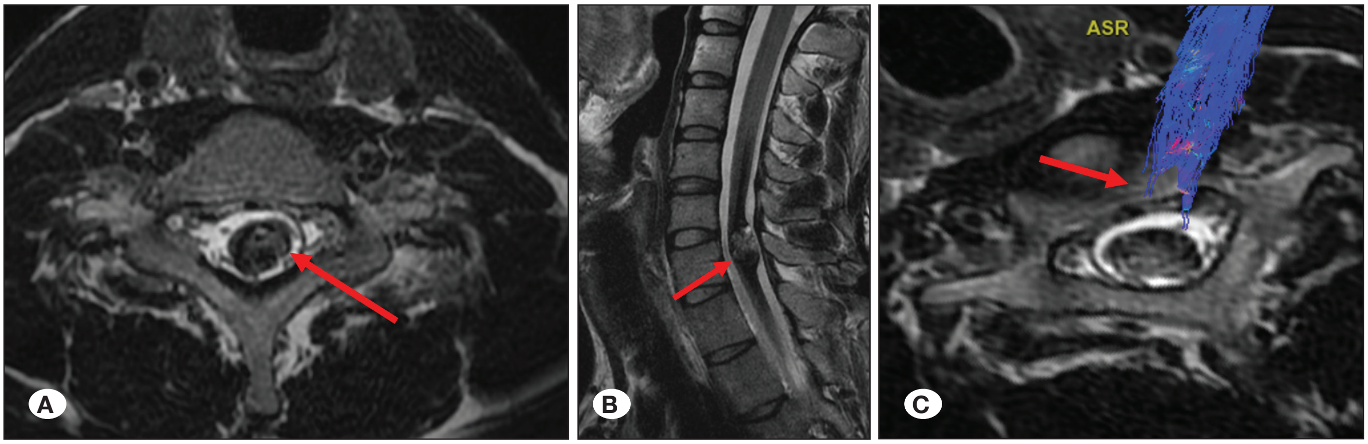

Figure 3: Axial **(A)** and sagittal plane **(B)** T2-weighted MR images reveal pathologically proven cervical spinal ependymoma (arrows) in a 34-year-old male patient with normal neurological examination. Axial plane diffusion tensor tractography image **(C)** demonstrates interruption (arrow) of the fiber tracts at the level of the lesion.

The mean FA was 0.34 ± 0.45 in this study, which was less than that demonstrated by D'souza et al. (5), who reported a mean FA of 0.43 ± 0.08 in a retrospective study involving 20 patients with acute CSC trauma (5). The reason for the diminished FA in the present study was probably the presence of seven cavernomas. Blood contents within the cavernous malformation limit the diffusivity of water molecules. Moreover, in patients with acute CSC injury, diffusivity at the site of axonal injury is prevented by blood products, resulting in decreased FA values in both adults and children (3,9,12,20). When only the seven cavernomas were included in the FA calculation, the mean FA further decreased to 0.25 ± 0.09. Zdunczyk et al. reported a mean FA of 0.32 in a study of 21 brainstem cavernous malformations. They mentioned that the mean FA further diminished to 0.16 in patients with motor deficits and that a significant inverse correlation existed between FA and motor deficits (21). However, we detected normal neurological findings in 28.6% (2/7) of CSC cavernomas in this case series.

Rogalska et al. conducted a review of 14 articles and found that the PPV and NPV of DTT were in the range of 20%–75% and 66.6%–100%, respectively, in patients with brainstem cavernomas (14). Similarly, we found a PPV of 38.7% in this series. A low PPV precludes reliable and reproducible prediction of neurological deficits. Qualitative DTI provides valuable information regarding the alignment of the ascending and descending fiber tracts in the spinal cord. It also enables the neurosurgeon to decide and plan the most appropriate and safest entry zone into the spinal cord. Jang and Kwon demonstrated that DTT could be used not only for the navigation and course of the fiber tracts but also for the calculation of fiber volume. In addition, in this study, they found a positive correlation between the ascending reticular activating system FA value and the Glascow coma scale score (8).

Akshiitha et al. reported a significant negative correlation between FA and clinical score at the level of cervical spinal stenosis in patients with compressive myelopathy (1). They reported mean FA and ADC of 0.49 ± 0.13 and 1.20 ± 0.16, respectively, at the level of stenosis, which were respectively higher and lower than those observed in our study. The elevated ADC in our study is probably because of the presence of ependymomas. The mean ADC for ependymomas in this case series was 1.80 ± 0.76, which caused an increase in the total mean value. Spinal cord astrocytomas have an infiltrative pattern, and consequently, the white matter tracts are impaired, whereas ependymomas originate from the ependymal lining of the central canal and have a tendency to displace the white matter tracts (2,7,16). Similarly, most patients with astrocytomas (4/6) had deformed or interrupted fiber tracts compared with most patients with ependymomas (7/13) who showed deviation of the fiber tracts in this series. Zhao et al. reported that CSC astrocytomas exhibited decreased FA and increased ADC in their study involving 11 patients (22). In the present study also, patients with astrocytomas exhibited decreased FA, with the mean value being 0.22 ± 0.04.

Czernicki et al. found that when pyramidal tracts demonstrate more disruption on DTT, motor deficits were significantly more frequent (4). In contrast, intramedullary CSC tumors demonstrating more disruption of the white matter tracts as deformation and interruption in this case series did not correlate with the degree of motor deficits. We found that patients with motor deficits (6/31) had deviated (n=2), deformed (n=2), and interrupted (n=2) tracts.

This study had some limitations. First, the number of patients was small. Second this was a retrospective study and lacked randomization. Finally, our results must be validated in larger prospective series. However, the lack of a consistent correlation between qualitative DTT and NEF in our study suggests that further investigation and refinement of this technique and a larger patient series are warranted.

CONCLUSION

Although DTT of the CSC might be useful for surgical planning and preservation of the fiber tracts during surgery, it did not demonstrate a significant association with clinical findings in this case series.

Declarations

Funding: No funding or support was received for this manuscript, and the authors have no financial or non-financial interests to disclose.

Availability of data and materials: The data are not publicly available, but anonymized data can be obtained from the corresponding author upon reasonable request.

Disclosure: There are no conflicts of interest or disclosures related to this manuscript.

AUTHORSHIP CONTRIBUTION

Study conception and design: ZF, OMT

Data collection: ZF, OMT, CKY

Analysis and interpretation of results: ZF, OMT, CKY, AG

Draft manuscript preparation: ZF, OMT, CKY

Critical revision of the article: GE, UT

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

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