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Research Article

Comparison and Clinical Utility of Pre- and Postoperative Diffusion Tensor Imaging MRI Findings in Patients with Cervical Spondylotic Myelopathy

Cevat Akinci[1], Giyas Ayberk[2], Ismail Bozkurt[3], Karabekir Ercan[4], Abdullah Emre Tacyildiz[1]

[1]Karabük University, Faculty of Medicine, Department of Neurosurgery, Karabük, Türkiye
[2]Ankara Bilkent City Hospital, Department of Neurosurgery, Ankara, Türkiye
[3]Medical Park Ankara Hospital, Department of Neurosurgery, Ankara, Türkiye
[4]Ankara Bilkent City Hospital, Department of Radiology, Ankara, Türkiye

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Abstract

Aim: This study aimed to present the cervical diffusion tensor imaging (DTI) results in cervical spondylotic myelopathy (CSM) patients scheduled for operation and follow-up.

Material and Method: This clinical cohort type study was conducted between January 2016 and May 2016 in the neurosurgery clinic of a tertiary hospital. The study included 27 patients diagnosed with cervical spondylotic myelopathy. Surgical treatment was recommended to 15 patients and follow-up to the remaining. Cervical magnetic resonance imaging (MRI) and diffusion tensor imaging (DTI) scans were performed, and anteroposterior canal diameters, apparent diffusion coefficient (ADC), and fractional anisotropy (FA) values were calculated.

Results: The mean age was 62.37±7.39, and 22.2% (n=6) were women. Hoffmann pathological reflex was detected in 11 (40.7%) patients. The preoperative and postoperative AP (4.18±0.85 vs. 6.66±1.00, p<0.001), ADC (1.49±0.16 vs. 1.30±0.11, p=0.001), and FA (0.36±0.04 vs. 0.43±0.04, p=0.001) values were significantly different. The FA values of patients scheduled for follow-up were significantly higher than those who were recommended surgery (0.43±0.04 vs. 0.37±0.04, p=0.001). A negative correlation was found between FA and ADC values in both preoperative (r=-0.618, p<0.001) and postoperative (r=-0.748, p=0.013) measurements.

Conclusion: DTI is a radiological tool that can aid in diagnosing CSM and identifying patients requiring surgery or follow-up. Due to its expected clinical benefits, we recommend a more widespread application of this method in patients with CSM.

Keywords: Diffusion tensor imaging, spinal cord diseases, myelopathy, surgery

INTRODUCTION

Cervical spondylosis is a gradually advancing degenerative disorder that results in neural compression secondary to the progressive narrowing of the spinal canal (1). Cervical spondylosis represents a significant etiological factor in spinal cord dysfunction and acquired spastic paraparesis in adults (2). Moreover, degenerative spondylotic alterations are among the primary contributors to the development of myelopathy (3).

Magnetic resonance imaging (MRI) is the preferred diagnostic modality for evaluating suspected cases of cervical spondylotic myelopathy (CSM). This imaging technique provides multiple advantages, including high-resolution multi-planar visualization, precise delineation of neural structures, a noninvasive nature, and the benefit of avoiding ionizing radiation exposure (4). Although MRI is considered the gold standard for diagnosing CSM, it has certain limitations, most notably its relatively low sensitivity in identifying subtle structural alterations within the spinal cord and surrounding tissues (4). As a result, early diagnosis of CSM before the manifestation of clinical symptoms or the development of histopathological changes in the spinal cord remains a significant challenge. Diffusion-weighted imaging (DWI), an advanced MRI technique that utilizes the Brownian motion of water molecules (Figure 1) to generate contrast, has shown superior sensitivity in detecting early microstructural abnormalities (5,6).

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Corresponding Author: Abdullah Emre Tacyildiz, Karabük University, Faculty of Medicine, Department of Neurosurgery, Karabük, Türkiye
E-mail: abdullahemretacyildiz@gmail.com

This technique allows for in vivo, noninvasive mapping of water molecule movement within biological tissues. The diffusion properties of water molecules serve as an indicator of tissue microarchitecture, and pathological conditions can significantly disrupt this process, providing valuable insights into underlying structural abnormalities (5). Diffusion tensor imaging (DTI), an advanced variant of DWI, is widely utilized for the detailed visualization and assessment of white matter tracts within the brain and spinal cord, allowing for the evaluation of their microstructural integrity and connectivity (7). Notably, advanced MRI modalities, including DWI and DTI, have demonstrated the potential to enable earlier detection of myelopathy while also enhancing the understanding of its underlying pathological mechanisms (8,9).

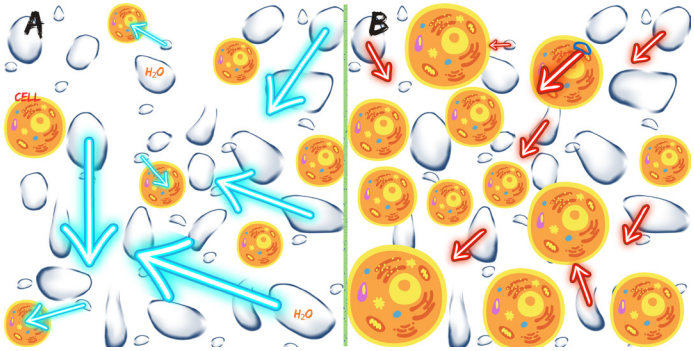


Figure 1. A. The unrestricted diffusion of water molecules in all directions within the tissue is observed; **B.** A restriction in water molecule movement is observed, accompanied by an increase in anisotropic diffusion along a single direction within the interstitial space

This study aimed to evaluate cervical DTI findings in patients diagnosed with CSM who were either scheduled for surgical intervention or under clinical follow-up. The objective was to provide imaging-based insights to enhance clinical decision-making for physicians and patients.

MATERIAL AND METHOD

Study Design and Patient Population

Our study is a single-center, non-randomized, prospective clinical investigation. The study enrolled 27 patients diagnosed with cervical spondylotic myelopathy, who were followed for at least six months at the Neurosurgery Clinic of Atatürk Training and Research Hospital, operating under the General Secretariat of the Turkish Ministry of Health's Public Hospitals Union, between January 2015 and May 2016. Patients were monitored for at least 6 months. A control group of 10 individuals with normal cervical MRI findings and no active complaints was also included. This research adhered to established ethical guidelines and received formal approval from the hospital's ethics committee. Ethical approval (No: 165 – Date: 11.05.2016) was received from the Yıldırım Beyazit University Faculty of Medicine, Atatürk Training and Research Hospital Clinical Research Ethics Committee. Informed consent was obtained from all participants prior to their inclusion in the study. Yıldırım Beyazıt University Ankara Atatürk Training and Research Hospital Neurosurgery Clinic is a 30-bed facility that provides outpatient services to approximately 30,000 patients annually.

Participants

The study included 27 patients diagnosed with CSM who were followed for a minimum of six months. Patients aged 40–80 years with at least two levels of CSM and no prior surgical intervention for cervical pathology were eligible for inclusion. Exclusion criteria included patients with a history of surgery for conditions such as neoplasia, infection, traumatic or pathological collapse fractures; those with prior anterior cervical discectomy, foraminotomy, or laminotomy; and patients with poor general health status.

Surgery was recommended for patients with Modified Japanese Orthopedic Association (mJOA) scores of 17 or below, severe clinical symptoms, upper extremity motor strength graded at 4/5 or lower, and a positive Hoffman pathological reflex. Fifteen patients met these criteria, of whom 5 declined surgical intervention. The remaining 10 patients underwent surgery, with 8 receiving open-door laminoplasty and 2 undergoing posterior laminectomy with posterior lateral mass instrumentation. The remaining 12 patients, who did not meet surgical criteria or opted against surgery, were advised to continue with follow-up. Patients who underwent surgical interventions were invited for postoperative follow-up visits and repeat radiological evaluations.

Group 1: Preoperative and postoperative cervical fractional anisotropy (FA) and apparent diffusion coefficient (ADC) measurements were compared in patients who underwent surgery.

Group 2.1: Patients who met surgical criteria but declined surgery.

Group 2.2: Patients who did not meet surgical criteria and were advised for follow-up. Preoperative FA and ADC measurements of these patients were compared with those who underwent surgery.

Group 3: FA and ADC measurements of the asymptomatic control group (Group 3 consists of a 10-member voluntary control group) were compared with those of patients diagnosed with CSM.

Variables

Cervical MRI and DTI were performed for all participants. The anteroposterior (AP) canal diameters, ADC values, and FA values scores were calculated. Additionally, the presence of Hoffman pathological reflexes in patients with CSM was recorded. The primary outcome variable of the study was the ADC values.

In our study, DTI measurements were performed on the cervical cord using a standardized protocol to ensure consistency across all subjects. To minimize variability, we employed the same MRI scanner and acquisition parameters for all patients. Additionally, regions of interest (ROIs) were manually placed by an experienced radiologist following predefined anatomical landmarks to maintain uniformity. To further enhance reproducibility, we utilized inter- and intra-observer reliability assessments.

Statistical Analysis

The suitability of variables, including AP canal diameter, ADC, and FA for normal distribution was assessed using the Shapiro-Wilk test. For variables that did not follow a normal distribution, descriptive statistics were presented as median (interquartile range, IQR). For normally distributed variables, mean±standard deviation (SD) values were provided. Frequency (n) and percentage (%) were used to describe categorical variables, such as patient groups and the presence of Hoffman pathological reflex. Differences in AP canal diameter, ADC, and FA values before and after surgery were analyzed using the paired samples t-test, and the corresponding mean value graphs were generated. The independent samples t-test was used to compare ADC and FA values between the surgical + surgery-declined group and the follow-up group, with relevant mean value graphs plotted. Similarly, differences in ADC and FA values between the CSM group and the control group were also analyzed using the independent samples t-test, and corresponding graphs were created. Correlation analyses were performed to evaluate the relationships between preoperative and postoperative ADC and FA values. Pearson correlation coefficients were calculated for these relationships. All statistical analyses were conducted using IBM SPSS Statistics, Version 21.0 (IBM Corp., Armonk, NY, USA), and Microsoft Excel 2007 software.

RESULTS

Table 1 summarizes the demographic characteristics of the patient and control groups.

Of the individuals included in the study, 27.0% (n=10) were in the surgical group, 13.6% (n=5) were in the surgery-declined patient group, and 32.4% (n=12) were in the follow-up patient group. The control group consisted of ten asymptomatic individuals. In 26 individuals (70.3%), Hoffman reflex was positive, while in 11 individuals (29.7%), it was negative.

Table 1. Demographic data of patient and control groups

Groups	n	Mean age±Standard deviation (SD)	Male (n)	Female (n)
Group 1: Patients who met the surgical criteria and underwent surgery	10	61.6±10.7	8	2
Group 2.1: Patients who met the surgical criteria, were recommended surgery but declined the procedure	5	59.4±12.4	4	1
Group 2.2: Asymptomatic CSM patients who were not recommended for surgery and chose follow-up	12	62.0±11.5	8	4
Group 3: Asymptomatic volunteer individuals with no known diagnosis of CSM	10	58.6±11.4	5	5

The mean AP canal diameter of the 37 individuals included in the study was 6.61±2.62 mm (range: 3.30–12.90 mm). The mean ADC was 1.35±0.23×10^{-3} mm^2/s (range: 0.85–1.72×10^{-3} mm^2/s), while the mean FA was 0.42±0.06 (range: 0.31–0.54).

The preoperative mean AP canal diameter of the 10 patients who underwent surgery was 4.18±0.85 mm, increasing to 6.66±1.00 mm postoperatively. This postoperative increase in AP canal diameter was statistically significant (p<0.001) (Table 2). The preoperative mean ADC value of the patients was 1.49±0.16×10^{-3} mm^2/s, while the postoperative mean was 1.30±0.11×10^{-3} mm^2/s. A statistically significant difference was observed between the preoperative and postoperative ADC values (p=0.001), with higher ADC values recorded preoperatively (Table 2). The preoperative mean FA value was 0.36±0.04, increasing to 0.43±0.04 postoperatively. This change was also statistically significant (p=0.001), with lower FA values observed preoperatively compared to postoperative values (Table 2).

Table 2. Comparison of preoperative and postoperative AP, ADC, and FA values

Parameter	Preoperative Mean±SD	Postoperative Mean±SD	t	p
AP (mm)	4.18±0.85	6.66±1.00	8.537	**<0.001**
ADC (×10^{-3} mm^2/s)	1.49±0.16	1.30±0.11	3.066	**0.001**
FA (unitless)	0.36±0.04	0.43±0.04	4.739	**0.001**

t: Paired-sample t-test, SD: standard deviation, AP: anterior-posterior spinal diameter, ADC: apparent diffusion coefficient, FA: fractional anisotropy

The mean ADC value in patients who underwent surgery or declined surgery (Group 2) was 1.49±0.14×10^{-3} mm^2/s, compared to 1.42±0.14×10^{-3} mm^2/s in the follow-up group (patients not recommended for surgery). There was no statistically significant difference in ADC values between the two groups (p=0.209) (Table 3). The mean FA value in the surgical and surgery-declined group was 0.37±0.04, while it was 0.43±0.04 in the follow-up group. A statistically significant difference in FA values was observed between the groups (p=0.001), with higher FA values recorded in the follow-up group (Table 3).

Table 3. Comparison of ADC and FA values of patients scheduled for surgery or follow-up				
Parameter	**Recommended surgery (n=15) Mean±SD**	**Recommended follow-up (n=12) Mean±SD**	**t**	**p**
ADC ($\times10^{-3}$ mm^2/s)	1.49±0.14	1.42±0.14	1.288	0.209
FA (unitless)	0.37±0.03	0.43±0.04	3.964	**0.001**
t: Independent-samples t-test, SD: standard deviation, ADC: apparent diffusion coefficient, FA: fractional anisotropy				

In Group 3, the mean ADC value for the 10 individuals in the control group was 1.06±0.15×10^{-3} mm^2/s, compared to 1.46±0.14×10^{-3} mm^2/s for individuals diagnosed with CSM. A statistically significant difference in ADC values was observed between the control group and the CSM-diagnosed group (p<0.001). ADC values in the control group were significantly lower than those of patients diagnosed with CSM (Table 4).

Table 4. Comparison of ADC and FA values between the control group and patients with CSM and correlation analysis between FA and ADC in preoperative and postoperative states				
Parameter	**Control Group (n=10) Mean±SD**	**Cervical Spondylosis Group (n=27) Mean±SD**	**t**	**p**
ADC ($\times10^{-3}$ mm^2/s)	1.06±0.15	1.46±0.14	7.294	**<0.001**
FA (unitless)	0.48±0.04	0.40±0.05	4.520	**<0.001**
t: Independent-samples t-test, SD: standard deviation, ADC: apparent diffusion coefficient, FA: fractional anisotropy				

A statistically significant moderate negative linear correlation was observed between preoperative fractional anisotropy (FA) values and ADC values (r=-0.618, p<0.001). This indicates that as preoperative FA values increased, preoperative ADC values decreased, and vice versa. Similarly, a strong, negative, linear, and statistically significant correlation was identified between postoperative FA and ADC values (r=-0.748, p=0.013). This suggests that as postoperative FA values increased, postoperative ADC values decreased, and vice versa (Table 5).

Table 5. Correlation analysis between FA and ADC in preoperative and postoperative states		
Parameter	**Pearson correlation coefficient (r)**	**p**
Preoperative FA and ADC	-0.618	<0.001
Postoperative FA and ADC	-0.748	0.013
ADC: apparent diffusion coefficient, FA: fractional anisotropy		

DISCUSSION

The preoperative mean AP canal diameter of the 10 patients who underwent surgery was calculated as 4.18±0.85 mm, increasing to 6.66±1.00 mm postoperatively. The mean ADC value was 1.49±0.16×10^{-3} mm^2/s preoperatively and 1.30±0.11×10^{-3} mm^2/s postoperatively. The mean FA value increased from 0.36±0.04 preoperatively to 0.43±0.04 postoperatively. The differences in preoperative and postoperative AP canal diameter, FA, and ADC values were statistically significant (Table 2).

In our study, the mean FA value in Group 2, which included patients who underwent surgery and those who were recommended surgery but declined, was 0.37±0.04. In contrast, the mean FA value of patients who were not recommended surgery and were advised for follow-up was 0.43±0.04. A statistically significant difference in FA values was observed between the groups, with higher FA values recorded in the follow-up group (Table 3).

In our study, the mean ADC value of the 10 individuals in Group 3 (control group) was 1.06±0.15×10^{-3} mm^2/s, whereas the mean ADC value of patients diagnosed with CSM was 1.46±0.14×10^{-3} mm^2/s. The difference in ADC values between the two groups was statistically significant, with lower ADC values observed in the control group compared to those diagnosed with CSM (Table 4).

Despite being the gold standard for imaging cervical cord pathology, MRI has inherent limitations in quantifying disease severity, offering precise prognostic insights, and capturing early microstructural abnormalities in CSM (10). As a highly sensitive imaging modality, DTI has become increasingly recognized for its ability to reveal microstructural abnormalities beyond the resolution of conventional MRI, utilizing advanced quantitative parameters (10). Significant alterations in DTI metrics can be identified in CSM preceding the development of T2 hyperintensity, emphasizing its role in early disease characterization (11). Using DTI, Kara et al. examined 16 patients diagnosed with CSM who exhibited no spinal cord hyperintensity on T2-weighted MRI, comparing stenotic and non-stenotic cervical canal regions (11). Their findings revealed significant differences in FA and ADC values

between stenotic and non-stenotic segments. Specifically, FA values decreased, while ADC values increased at stenotic levels (11). A meta-analysis of studies investigating DTI in patients with SCM reported a reduction in FA values and an elevation in ADC values (12).

In our study, a comparison of DTI results between the control group (n=10) and patients diagnosed with cervical spondylotic myelopathy (CSM, n=27)—including those who accepted surgery, those who declined surgery, and those advised for follow-up—revealed statistically significant differences in FA and ADC values (Table 4). These findings are consistent with previously reported literature.

The diagnostic utility of MRI, particularly in detecting signal anomalies, remains a subject of debate. While MRI may not reveal definitive evidence of SCM, studies have demonstrated alterations in FA and radial diffusivity (RD) (11,13-15). Shabani et al. assessed perioperative FA values in conjunction with T2 signal intensity on MRI, emphasizing FA as a crucial and reliable prognostic indicator (16). Demir et al. reported that the ADC had an 80% sensitivity in detecting clinically positive myelopathy patients, outperforming T2-weighted imaging at 61%. (9). However, while T2-weighted imaging exhibited a significantly higher specificity (92%) compared to ADC (53%), the lower specificity of ADC is attributed to technical limitations or early spinal cord changes preceding clinical or electrophysiological manifestations (9). However, in our study, MRI values were not measured, which we acknowledge as a limitation of our research.

In a prospective study by Lee et al., FA and ADC values significantly differed between healthy volunteers and patients with SCM, highlighting microstructural alterations in the diseased group (17). Our findings are consistent with those of Lee et al., as presented in Table 4. Similarly, Ellingson et al. highlighted the pivotal role of DTI in assessing disease progression and predicting outcomes in patients who chose to forgo surgical intervention (18). In our study, patients with SCM who were advised for follow-up due to mild findings were compared with those recommended for surgery, revealing a significant difference in FA values and a statistically significant variation in ADC values (Table 3). Similarly, Hori et al. reported that in patients classified based on severe clinical symptoms, FA exhibited a marked decrease, whereas ADC demonstrated an increase (19).

Shabani et al. observed that research examining preoperative and postoperative DTI parameters remains relatively limited (10). Kitamura et al. found no substantial alterations in FA values between the preoperative and postoperative phases in patients who underwent surgery for SCM (20). Wang et al. likewise identified no meaningful correlation between preoperative and postoperative FA and mean diffusivity (MD) parameters in their study (21). In contrast, our study revealed a statistically significant variation in FA and ADC values between the preoperative and postoperative phases (Table 2). Aligned with our results, Guan et al. likewise reported notable variations in FA values between the preoperative and postoperative periods (22). Our study revealed statistically significant improvements in preoperative and postoperative FA and ADC values among patients who underwent surgical intervention (Table 2).

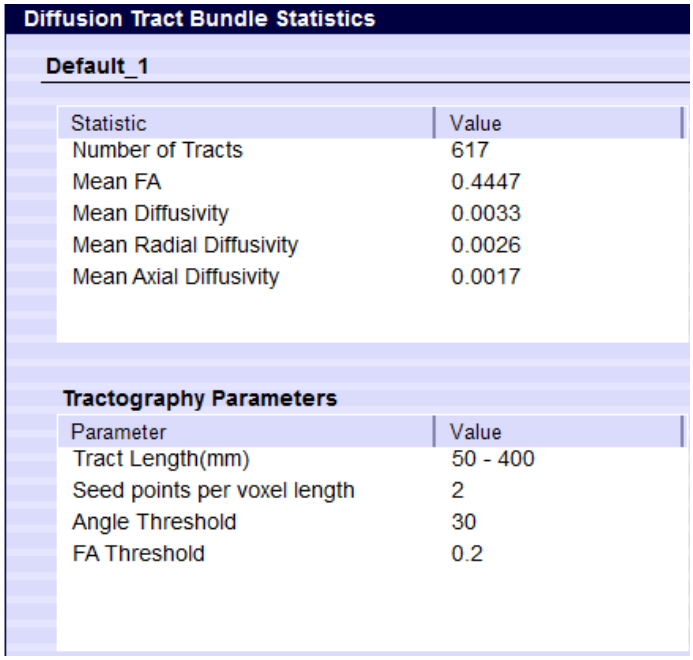
Jones et al. established a robust correlation between FA and baseline mJOA and Nurick scores (23). Postoperative enhancements in NDI scores, indicative of functional recovery, correlated with preoperative FA values. In patients with severe CSM, those exhibiting disproportionately elevated preoperative FA values attained higher postoperative mJOA scores compared to individuals with lower FA values (23). FA values serve as valuable biomarkers for assessing disease prognosis and predicting clinical outcomes in CSM (10,23). Preoperative FA is the most consistently and strongly correlated parameter with functional outcomes following cervical spondylotic myelopathy surgery (24). Fang et al. employed automated ROI analysis to quantify DTI metrics, including axial diffusion (AD), MD, RD, and FA in CSM patients (25). Their findings indicated elevated AD, MD, and RD values alongside reduced FA values, and uniquely, they identified AD in the DTI-Dorsal Column as the most promising marker for detecting affected segments, diverging from prior literature (25).

Wang et al. recognized reduced FA in the extension position as a robust predictor of restricted neurological recovery after surgery in CSM patients (26). Shao et al. demonstrated that MUSE-DTI provides superior imaging quality relative to conventional DTI and functions as a dependable metric for evaluating disease severity in SCM (27).

Multiple factors persist in complicating DTI measurements, including the distinction between single-level and multilevel disease, the severity and location of maximum compression, patient age, and the specific cervical level assessed, all of which can significantly impact DTI parameters (10,28-30).

When comparing SCM patients recommended for surgery with those not recommended for surgery, FA values were found to be statistically significant, while ADC values were not (Table 3). Additionally, a negative, moderate, linear, and statistically significant relationship was identified between preoperative FA and ADC values. In conclusion, these parameters play a crucial role in facilitating the diagnosis of CSM and enhancing the quality of follow-up care (Tables 4 and 5).

FA and ADC are key DTI metrics that provide valuable insights into microstructural integrity and pathological alterations in the cervical cord (Table 2-4). A decrease in FA typically indicates axonal damage and loss of white matter integrity, while an increase in ADC suggests extracellular edema or neurodegeneration (Figure 1, 2) (Table 2-4). These metrics can aid in assessing disease severity, monitoring progression, and guiding therapeutic strategies (Table 2-4).



Diffusion Tract Bundle Statistics

Default_1

Statistic	Value
Number of Tracts	617
Mean FA	0.4447
Mean Diffusivity	0.0033
Mean Radial Diffusivity	0.0026
Mean Axial Diffusivity	0.0017

Tractography Parameters

Parameter	Value
Tract Length(mm)	50 - 400
Seed points per voxel length	2
Angle Threshold	30
FA Threshold	0.2

Figure 2. FA measurements are monitored using the DWI imaging method via the hospital's electronic database; The two key parameters in DWI are fractional anisotropy (FA) and apparent diffusion coefficient (ADC); FA, an anisotropic parameter, ranges from 0 to 1. A value of 0 indicates unrestricted diffusion, whereas values near 1 suggest a highly anisotropic structure

Our study has several limitations. The primary limitation is the small sample size of both the patient and control groups. Additionally, the lack of a comparison between DTI results and MRI findings represents another constraint. Furthermore, the absence of JOA score evaluation in our study is a noteworthy limitation. We could have delineated the cohort groups more clearly, allowing for a more detailed presentation of the comparisons.

CONCLUSION

Our study demonstrated elevated FA and reduced ADC values in SCM patients compared to healthy controls. Significant alterations in FA and ADC values were evident in both preoperative and postoperative assessments. While FA values differed significantly between SCM patients recommended for surgery and those advised against it, ADC values did not show statistical significance. Furthermore, a moderate, negative, and statistically significant linear correlation was identified between preoperative FA and ADC values. In conclusion, these metrics serve as critical biomarkers for diagnosing CSM and optimizing follow-up care.

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Conflict of interest: *The authors have no conflicts of interest to declare.*

Ethical approval: *Ethical approval (No: 165–Date: 11.05.2016) was received from the Yıldırım Beyazit University Faculty of Medicine, Atatürk Training and Research Hospital Clinical Research Ethics Committee.*

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