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Original Article

Radiology Section

Role of Diffusion Tensor Imaging in Early Detection of Cervical Spondylotic Myelopathy: An Observational Study

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ABSTRACT

Introduction: Cervical Spondylotic Myelopathy (CSM) is a common degenerative spinal condition that can lead to significant neurological deficits if not detected early. Conventional Magnetic Resonance Imaging (MRI), while useful, has limited sensitivity in detecting early myelopathic changes. Diffusion Tensor Imaging (DTI), a novel MRI technique, offers quantitative parameters such as Fractional Anisotropy (FA) and Apparent Diffusion Coefficient (ADC), which may aid in the early detection and severity assessment of CSM.

Aim: To estimate and compare DTI parameters (FA and ADC) at stenotic and non stenotic levels in patients with CSM and to correlate these parameters with clinical severity using the modified Japanese Orthopaedic Association (mJOA) score.

Materials and Methods: An observational study was conducted at a Chettinad hospital and research institute involving 30 patients with CSM. Ethical clearance and informed consent were obtained. Patients underwent conventional MRI and DTI sequences using a 3T Philips MRI scanner. The FA and ADC values were measured at stenotic and non stenotic levels. Clinical severity was assessed using the mJOA score. Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) version 27, with paired sample t-tests and Pearson's correlation ($p<0.05$ considered significant).

Results: The mean FA value was significantly lower at stenotic levels (0.46) compared to non stenotic levels (0.61) ($p=0.001$). Conversely, the mean ADC value was significantly higher at stenotic levels (1.35) compared to non stenotic levels (1.02) ($p=0.001$). A strong positive correlation was observed between FA values at stenotic levels and mJOA scores ($r=0.946$, $p=0.001$), while a strong negative correlation was found between ADC values and mJOA scores ($r=-0.920$, $p=0.001$).

Conclusion: DTI parameters (FA and ADC) demonstrated significant changes at stenotic levels in CSM patients and correlated strongly with clinical severity. DTI holds promise as a quantitative tool for early detection and severity assessment of CSM.

Keywords: Apparent diffusion coefficient, Fractional anisotropy, Neuroimaging, Spinal cord compression

INTRODUCTION

The CSM stands out as one of the common degenerative spinal problem [1-3]. It arises from prolonged compression in the nerve roots which are exiting and traversing from the cord within the spinal canal, which gives the outcome of spondylotic compressive myelopathic changes [4]. Patients typically present with complaints like pain radiating to limbs upper or lower limbs, sometimes both, particularly in the upper limbs, coupled with neck discomfort and stiffness [5]. Clinical signs may include urinary urgency, upper limb numbness or loss of fine motor skills, muscle weakness, and an unsteady gait [6,7].

The diagnosis of CSM is typically monitored using clinical symptoms and imaging modalities, primarily plain radiography and conventional Magnetic Resonance Imaging (MRI). While conventional MRI is the modality of choice for identifying spondylotic changes and secondary complications to the spinal cord, it has a low sensitivity for detecting myelopathic changes, estimated at around 65% [8,9]. The high signal intensity in the cord on T2-Weighted (T2W) images, which indicates myelopathic changes, often appears only in the late clinical stages [10].

Early radiological diagnosis of CSM is critical, as surgical intervention in the earlier stages of the disease has been reported to yield better outcomes compared to later stages [10]. The DTI, an advanced MRI technique, has shown promise in the early detection of spinal cord abnormalities, as DTI parameters such as FA and ADC have been found to be more effective than conventional T2W in identifying early myelopathic changes [10].

The primary mechanisms underlying spinal cord injury in patients with CSM are spinal cord ischaemia and microtrauma, which result in the apoptosis of oligodendrocyte cells. These pathological changes are often visible as hyperintense signals on T2W images, indicating either cord edema or gliotic alterations [10]. Despite the utility of conventional MRI in assessing cervical spondylosis, its role in evaluating spinal cord involvement remains relatively limited [8-10].

The present study aimed to estimate and compare DTI parameters (FA and ADC values) at stenotic and non stenotic levels in patients with CSM and to correlate these parameters with the clinical assessment of disease severity using the mJOA [11]. By doing so, this study seeks to establish the role of DTI in the quantitative assessment of cervical spondylosis severity and its potential for early detection of CSM.

MATERIALS AND METHODS

An observational study was conducted in the Radiology Department of Chettinad hospital and research institute from January 2023-December 2023. The study included patients with CSM after obtaining ethical committee clearance and written informed consent. Ethical approval was obtained from the Institutional Ethics Committee (IHEC-I/1932/23).

Inclusion and Exclusion criteria: The inclusion criteria for the study were adult patients of either sex presenting with symptoms such as fine motor skill impairment, pain radiating to the shoulder and upper limb, neck stiffness, loss of balance, and difficulty walking. Exclusion criteria included patients with metallic implants, prostheses, claustrophobia, MR contraindications (e.g., cochlear implants, pacemakers), traumatic changes in the spinal cord, spinal cord tumours, or spondylodiscitis.

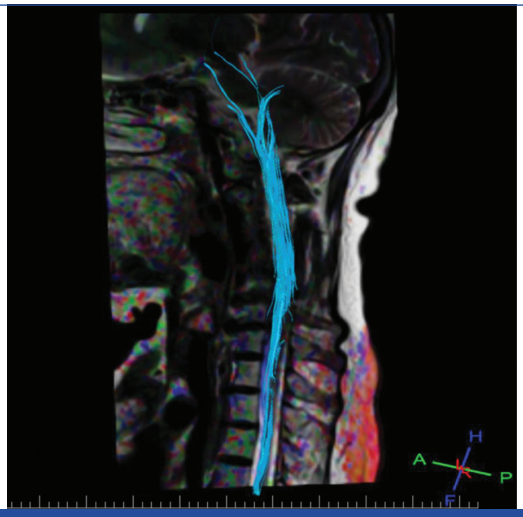
Sample size calculation: The sample size was calculated using an online sample size calculator (Statulator 2014) for comparing paired differences for means [12]. Based on a previous study by Toktas ZO et al., the mean FA value in stenotic segments was 0.4228±0.1090, and in non stenotic segments, it was 0.6884±0.0075. The mean ADC values were 1.312±0.2405 in stenotic segments and 0.9183±0.1477 in non stenotic segments. The study required a sample size of seven pairs to achieve a power of 90% and a significance level of 1% (two-sided) for detecting an effect size of 2.7 for FA values and five pairs for ADC values [13].

A total of 30 patients fulfilling the eligibility criteria were recruited consecutively using purposive sampling. Each participant underwent a thorough neurological examination conducted by a neurosurgeon, and the clinical diagnosis of CSM was established based on observed clinical symptoms. MRI scans were acquired using a 3T Philips MRI scanner (Ingenia, Netherlands) with a ds head neck spine coil. The imaging protocol included sagittal T2W, sagittal T1-Weighted (T1W), axial T2W Fast Spin Echo (FSE) sequences, and a 15-direction Echo Planar Imaging (EPI)-based DTI sequence in the axial plane.

Study Procedure

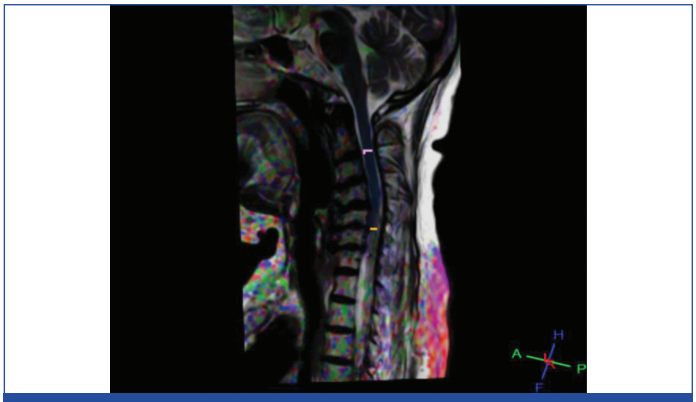
The DTI parameters were set as follows: axial plane imaging with a slice thickness of 4 mm, no slice gap (0 mm), an acquisition matrix of 128×128, a Field of View (FOV) of 230 mm, and three signal acquisitions. Diffusion measurements were performed along 15 non-collinear directions using two b-values (0 and 1,000 s/mm^2). The acquired DTI images were processed to generate ADC and FA maps for the axial slices. FA and ADC values were measured at both non stenotic (C2-C3) and stenotic segments of the cervical spinal cord.

For Diffusion Tensor Tractography (DTT), aberrant spinal cord signals were first detected on T2 or T1-weighted sequences due to degenerative changes. Synco MR neuro 3D software was used to post-process the DTI data. The b0 threshold was determined to eliminate artifact voxels corresponding to noise. Automated calculations were performed to generate FA and ADC maps. An ellipsoid or circle was created on Tensor images to represent the Region of Interest (ROI) for obtaining DTI data from the FA and ADC maps. The FA and ADC values were acquired using the DTT method at each level of stenotic and non stenotic cord regions [Table/Fig-1-3].



[Table/Fig-1]: Fibre tract visualisation using Diffusion Tensor Imaging (DTI).
(Source: Department of Radio-Diagnosis, CHRI)

The clinical severity of CSM was assessed using the mJOA score, which ranges from 0 to 18 [14]. A lower score indicates more severe deficits, with scores of 15-17 indicating mild myelopathy, 12-14 indicating moderate myelopathy, and 0-11 indicating severe myelopathy. The mJOA score evaluates upper and lower limb motor dysfunction, sensory dysfunction, and sphincter dysfunction. For upper limb motor dysfunction, a score of 0 indicates incapability of using hands, while a score of 5 indicates normal function. For lower limb motor dysfunction, a score of 0 indicates total loss of sensory and motor abilities, while a score of 7 indicates normal function. For upper limb sensory dysfunction, a score of 0 indicates total loss of hand sensation, while a score of 3 indicates normal sensation. For sphincter dysfunction, a score of 0 indicates inability to pass urine independently, while a score of 3 indicates normal bladder function.



[Table/Fig-2]: Marking of non stenotic and stenotic levels on axial MRI images.
(Source: Department of Radio-Diagnosis, CHRI)

Name	Voxels	FA	ADC [10^-3mm²/s]
√ ROI 05	5	0.622±0.117	1.050±0.217
√ ROI 06	3	0.329±0.156	1.715±0.313

[Table/Fig-3]: Fractional Anisotropy (FA) and Apparent Diffusion Coefficient (ADC) values at non stenotic (purple) and stenotic (yellow) levels as marked in above figure 2 of same patient.
(Source: Department of Radio-Diagnosis, CHRI)

STATISTICAL ANALYSIS

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) version 27. Quantitative variables were described using percentages, ranges, means, and standard deviations. Paired sample t-tests were used to compare FA and ADC values between stenotic and non stenotic levels. Pearson's correlation was used to assess the relationship between DTI parameters (FA and ADC) and the mJOA score. A p-value of <0.05 was considered statistically significant.

RESULTS

The study included 30 patients with CSM. The mean age of the study population was 45.83±13.97 years, ranging from 24 to 75 years. Nearly half of the participants (53.3%) belonged to the 41-60 years age group. The study population comprised 12 males (40%) and 18 females (60%), indicating a mild female predominance [Table/Fig-4].

Patients' characteristics		Frequency (n=30)	Percent (%)
Age group in years	18-40	6	20%
	41-60	16	53.3%
	61 and above	8	26.7%
	Minimum-maximum/mean/SD	24-75/45.83/13.97	
Gender	Male	12	40%
	Female	18	60%

[Table/Fig-4]: Demographic data of study population (n=30).

The mean FA value at the non-compression level was 0.61, while at the spinal cord compression level it was 0.46, indicating a significant decrease in FA at the stenotic level. Similarly, the mean ADC value at the non-compression level was 1.02 mm^2/s, while at the compression level it was 1.35 mm^2/s, showing a significant increase in ADC at the stenotic level [Table/Fig-5].

Paired sample t-tests revealed a statistically significant difference between FA values at non stenotic and stenotic levels (t=10.202, p=0.001) and between ADC values at non stenotic and stenotic levels (t=10.496, p=0.001) [Table/Fig-6].

Paired samples statistics		Mean	N	Std. Deviation	Std. Error mean
Pair 1	FA value at normal level	0.61440	30	0.013351	0.002438
	FA value at stenotic level	0.46660	30	0.077264	0.014106
Pair 2	ADC value at normal level	1.02450	30	0.038915	0.007105
	ADC value at stenotic level	1.35963	30	0.183417	0.033487

[Table/Fig-5]: Descriptive statistics of Diffusion Tensor Imaging (DTI) parameters (FA and ADC values) at non stenotic and stenotic levels.

Paired differences								
				95% Confidence interval of the difference				
Analysis	Mean	Std. Deviation	Std. Error mean	Lower	Upper	t	df	Sig. (2-tailed)
FA value at normal level - FA value at stenotic level	0.1478	0.079354	0.014488	0.118	0.1774	10.202	29	0.001
ADC value at normal level - ADC value at stenotic level	-0.335	0.174892	0.031931	-0.4004	-0.2698	-10.496	29	0.001

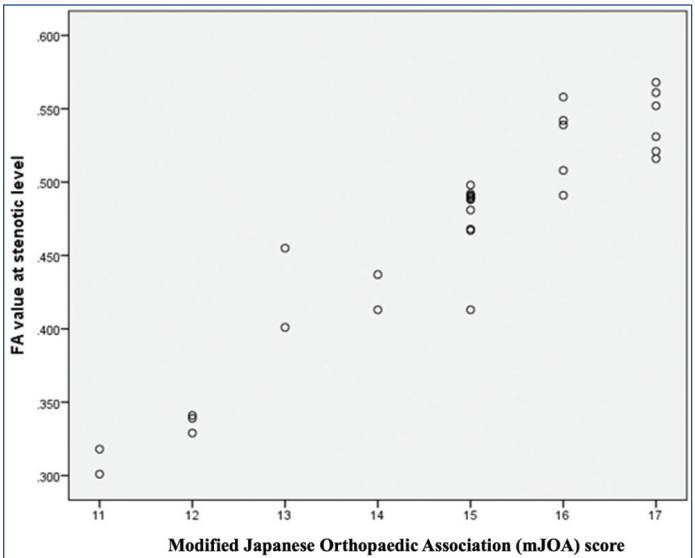
[Table/Fig-6]: Paired sample t-test results comparing FA and ADC values at non stenotic and stenotic levels.

A strong positive correlation was observed between FA values at stenotic levels and the mJOA score (r=0.946, p=0.001). Conversely, a strong negative correlation was found between ADC values at stenotic levels and the mJOA score (r=-0.920, p=0.001) [Table/Fig-7]. These findings suggest that lower FA values and higher ADC values at stenotic levels are associated with greater clinical severity of CSM.

Modified Japanese severity score versus DTI parameters	FA value at stenotic level	ADC value at stenotic level
Pearson correlation	0.946**	-0.920**
Sig. (2-tailed)	0.001	0.001
N	30	30

[Table/Fig-7]: Correlation between DTI parameters (FA and ADC values at stenotic levels) and the modified Japanese Orthopaedic Association (mJOA) score.
**Correlation is significant at the 0.01 level (2-tailed)

[Table/Fig-8] shows the scatter plot of FA values versus the mJOA score. The plot demonstrates a clear positive linear relationship, indicating that as FA values increase, the mJOA score (reflecting clinical improvement) also increases. This supports the notion that FA is a reliable indicator of spinal cord integrity and correlates well with clinical severity.



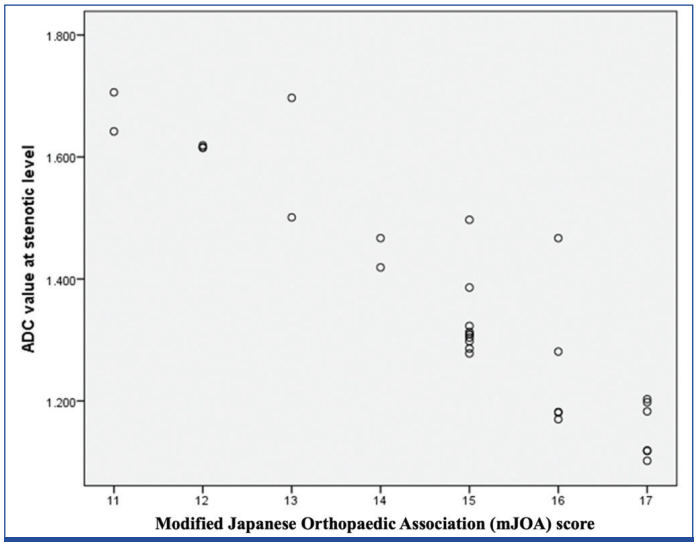
[Table/Fig-8]: Scatter plot showing the correlation between FA values at stenotic levels and the modified Japanese Orthopaedic Association (mJOA) score.

[Table/Fig-9] shows the scatter plot of ADC values versus the mJOA score. The plot reveals a negative linear relationship, indicating that as ADC values increase, the mJOA score decreases, reflecting worsening clinical severity. This further emphasises the role of ADC as a marker of microstructural damage in the spinal cord.

The results highlight the utility of DTI parameters (FA and ADC) in assessing the severity of CSM and their strong correlation with clinical outcomes. These findings suggest that DTI can provide valuable quantitative insights into spinal cord integrity.

DISCUSSION

The primary mechanisms underlying spinal cord injury in patients with CSM are spinal cord ischaemia and microtrauma, which result in the apoptosis of oligodendrocyte cells. These pathological



[Table/Fig-9]: Scatter plot showing the correlation between ADC values at stenotic levels and the modified Japanese Orthopaedic Association (mJOA) score.

changes are often visible as hyperintense signals on T2W images, indicating either cord oedema or gliotic alterations [9]. Despite the utility of conventional MRI in assessing cervical spondylosis, its role in evaluating spinal cord involvement remains relatively limited [15,16].

In this study, cervical spine MRI was recommended for individuals whose conditions were assessed using the mJOA score. Using areas of interest located in both stenotic and non stenotic segments, axial slices were collected, and DTI was employed to obtain values for FA and ADC. Correlations were then found by comparing the quantitative radiological data with the clinical grading system.

The study included 30 individuals with neck pain complaints. The mean age of the study population was 45.83±13.97 years, ranging from 24 to 75 years. Almost half of the population belonged to the age group of 41-60 years (53.3%). In a study by Nischal N et al., 52 individuals were included, with a mean age of 53.16 years and varying symptoms of myelopathy [17]. Similarly, Hassan TAAEH et al., reported a mean age of 44 years (range: 22-70 years) [18], and Sachin T et al., included 25 patients with a mean age of 52.2 years (range: 32-71 years) [15]. These findings suggest that CSM is more common in middle-aged individuals.

In the current study, 12 (40%) participants were males, and 18 (60%) were females, indicating a mild female predominance. This finding is consistent with previous studies. Nischal N et al., reported 24 males and 28 females out of 52 participants [17], while Sachin T et al., included 14 females and 11 males out of 25 patients [15]. Hassan TAAEH et al., also reported a higher prevalence in females, with 11 males and 19 females out of 30 patients [18]. This female predominance could be attributed to perimenopausal influences around that age group.

The mean FA value in the current study was 0.61 at the non-compression level and 0.46 at the spinal cord compression level, showing a significant decrease in FA at the stenotic level (t=10.202, p=0.001). These findings are consistent with previous studies. Nukala M et al., reported mean FA values of 0.729 at non stenotic levels and 0.48 at stenotic levels [1]. Gautam M et al., found mean FA values of 0.76±0.47 at non stenotic levels and 0.51±0.14 at stenotic levels [19]. Sachin T et al., reported mean FA values of 0.717±0.160 at non stenotic levels and 0.415±0.203 at stenotic levels (p<0.001) [15]. Nischal N et al., also observed significantly lower FA values at stenotic levels (0.5009±0.087) compared to non stenotic levels (0.6557±0.104, p<0.001) [17]. In a study by Hassan TAAEH et al., the mean FA value of the spinal cord opposite to normal disc levels was 0.742, and it was significantly reduced at the stenotic level. Similar findings were seen in a study by Uda T et al., [18,20]. On the other hand, other studies showed variability in the mean FA values of the spinal cord, such as 0.65 reported by Kara B et al., [10].

The mean ADC value in the current study was 1.02 at the non-compression level and 1.35 at the compression level, showing a significant increase in ADC at the stenotic level (t=10.496, p=0.001). These findings align with previous studies. Nukala M et al., reported mean ADC values of 0.9183±0.1477 at non stenotic levels and 1.312±0.2405 at stenotic levels [1]. Gautam M et al., found mean ADC values of 1.04 mm^2/s at non stenotic levels and 1.20 s/mm^2 at stenotic levels (p=0.001) [19]. Sachin T et al., reported mean ADC values of $1.010\pm0.458\times10^{-3}$ mm^2/s at non stenotic levels and $1.777\pm1.005\times10^{-3}$ mm^2/s at stenotic levels (p<0.001) [15].

The notable increase in ADC and decrease in FA at stenotic levels indicate microstructural damage and altered diffusion properties within the affected spinal cord regions, even in the absence of apparent abnormalities on conventional MRI. These findings are consistent with studies by Liang S et al., who reported a moderately positive correlation between FA at the most compressed level and the mJOA score (r=0.706, p=0.023 at C5; r=0.722, p=0.001 at C6; r=0.679, p=0.001 at C7) and a moderately negative correlation between ADC at the most compressed level and the mJOA score (r=-0.731, p=0.016 at C5; r=-0.415, p=0.044 at C6; r=-0.500, p=0.021 at C7) [21].

The strong positive correlation between FA values and the mJOA score (r=0.946, p=0.001) and the strong negative correlation between ADC values and the mJOA score (r=-0.920, p=0.001) in the current study further emphasise the potential role of DTI parameters in the early detection and severity assessment of CSM. These findings suggest that DTI can provide valuable quantitative insights into spinal cord integrity.

Limitation(s)

This study has a few limitations, including a relatively small sample size and the lack of long-term follow-up to assess the prognostic value of DTI parameters. Future studies with larger sample sizes and longitudinal follow-up are needed to validate these findings and explore the role of DTI in predicting surgical outcomes and disease progression.

CONCLUSION(S)

The present study demonstrated a significant decrease in FA and an increase in ADC values at stenotic levels in patients with CSM. The FA and ADC values showed a strong correlation with the mJOA score, indicating their potential role in assessing clinical severity. Notably, these DTI parameters revealed microstructural changes in the spinal cord. The findings suggest that DTI can serve as a valuable quantitative tool for the early detection and severity assessment of CSM. Its ability to detect subtle changes in spinal cord integrity makes it a promising modality for prognostic evaluation and treatment planning in patients with cord-related disorders. Further studies with larger sample sizes and long-term follow-up are recommended to validate these findings and explore the prognostic utility of DTI in CSM management.

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