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Prognostic Value of Craniovertebral Junction Diffusion Tensor Imaging in Patients with Chiari Type 1 Malformation

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ABSTRACT

AIM: To examine the spinal cord status by using diffusion tensor imagıng (DTI) and tractography preoperatively and postoperatively in patients with Chiari malformation type 1 (CM1) and compare the results with the data obtained from healthy people.

MATERIAL and METHODS: Overall, 48 patients (33 patients with CM1, and 15 in the control group for DTI and tractography measurements) were included in the study. Mean age was 37.7 ± 11.8 years (minimum and maximum: 12 and 57 years). The DTI and tractography data were obtained from the craniocervical region in patients with CM1 and control group. Patients with CM1 were operated using the suboccipital decompression technique without opening the dura. Surgical results were evaluated using Chicago Chiari Outcome Scale (CCOS) and Asgari scale.

RESULTS: Based on the CCOS and Asgari scale results, the surgical technique was determined to be clinically beneficial. The DTI and tractography values from the pontobulbar, cervicomedullary, and spinal cord C3–4 levels in patients with CM1 were compared to those of the control group. These values were observed to be near normal after surgery in patients with CM1.

CONCLUSION: Based on the improvement in DTI-tractography data observed in our study, DTI and tractography can serve as a guiding measurement method for assessing the prognosis of patients with CM1.

KEYWORDS: Chiari type 1 malformation, Diffusion tensor imaging, Tractography, Chicago chiari outcome scale, Asgari scale

INTRODUCTION

Chiari malformation is defined as the varying degrees of displacement of the posterior fossa structures through the foramen magnum into the cervical spinal canal. Chiari malformation type 1 (CM1) is considered to occur because of the small and shallow posterior cranial fossa. Smaller posterior fossa volume is generally the result of insufficient development of the occipital bone (24,26,29,37). The treatment options of CM1 vary based on the patient's symptoms, imaging, and neuropsychological tests. Several methods have been described as the optimal surgical treatment, some of which are controversial. Because of the lack of a standard outcome measure, there is no widely accepted tool to compare the results of each surgical method, which is a major limitation in Chiari research.

Diffusion tensor imagıng (DTI) and tractography have been used in several areas, especially those involving congenital anomalies. One of the most common purposes of using DTI and tractography is to evaluate the infiltration, destruction, or displacement of the white matter tracts. DTI indexes are affected by microstructural alterations that affect the diffusion of water molecules, and this forms the basis for using DTI indexes to identify spinal cord pathology. In the present study, we aimed to investigate the pre- and postoperative structural changes in white matter tracts in patients with CM1 by using DTI and tractography.

MATERIAL and METHODS

Overall, 48 patients (34 females, 14 males) were included in the study. The mean age was 37.7 years (± 11.8 years), with

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the youngest being 12 years old and the oldest 57. Cases were categorized into the following three groups:

Group-A: The control group, which revealed no pathology on the craniocervical MRI (Table I). The average tonsillar herniation in this group was –2.78 mm (± 2.19 mm; the lowest being –7 mm, and the highest 2 mm).

Group-B: Patients with CM1 without syringomyelia (Table I). The average tonsillar herniation was 12 mm (± 2 mm; the lowest being 10 mm, and the highest 15 mm).

Group-C: Patients with CM1 with syringomyelia (Table I). The average tonsillar herniation was 11 mm (± 2 mm; the lowest being 7 mm, and the highest 13 mm).

Craniospinal MRI and CT scans were obtained in all patients to evaluate the craniocervical junction (Figure 1).

DTI and tractography were performed in all patients with CM1 (Figure 2). Preoperative and early postoperative period apparent diffusion coefficient (ADC) and fractional anisotropy (FA) values at the pontobulbar region, cervicomedullary junction, and the C3–4 spinal cord level were calculated. ADC and FA diffusion maps were created in the axial plane and then reformatted as cervical tractography and diffusion maps on the sagittal plane to examine the craniocervical region by using DTI and tractography. For simplicity, pontobulbar level was named as ***‘a’***; cervicomedullary junction as ***‘b’***; and the C3–4 spinal cord level as the ***‘c’*** region.

A suboccipital craniectomy followed by C1 laminectomy was performed in all the patients with CM1.

DTI and tractography values were calculated at the end of the first postoperative month using the same method, and the clinical outcome was evaluated using Chicago Chiari Outcome Scale (CCOS) (Table II) and Asgari scale (Table III) at the end of the sixth postoperative month in all patients.

Statistical analysis was performed using the SPSS 17.0 statistical package software. Continuous variables were summarized as medians or means and SDs. The influence of all the categorical variables was tested using the chi-square test. A two-sided P value of <0.05 was considered to be statistically significant. A multivariate analysis was then carried out using a forward stepwise logistic regression analysis.

RESULTS

Besides tonsillar herniation, syringomyelia was observed in 16 patients, focal myelomalacia in 2, platybasia in 1, and the fourth ventricle expansion in 1.

Clinical Results

The average duration of symptoms was 3.7 years among all patients. Suboccipital headache when coughing, neck pain, and arm pain with numbness were the most frequent complaints (Table IV).

Table I: The Number of Cases and the Mean Ages of Each Group

Group Name	Number of Cases	Mean Age of the Group
Group-A	15 (9 women, 6 men)	37.8 ± 11.6 (the youngest 21, the oldest 56)
Group-B	17 (14 women, 3 men)	39.7 ± 10.7 (the youngest 17, the oldest 57)
Group-C	16 (11 women, 5 men)	35.3 ± 11.6 (the youngest 12, the oldest 55)

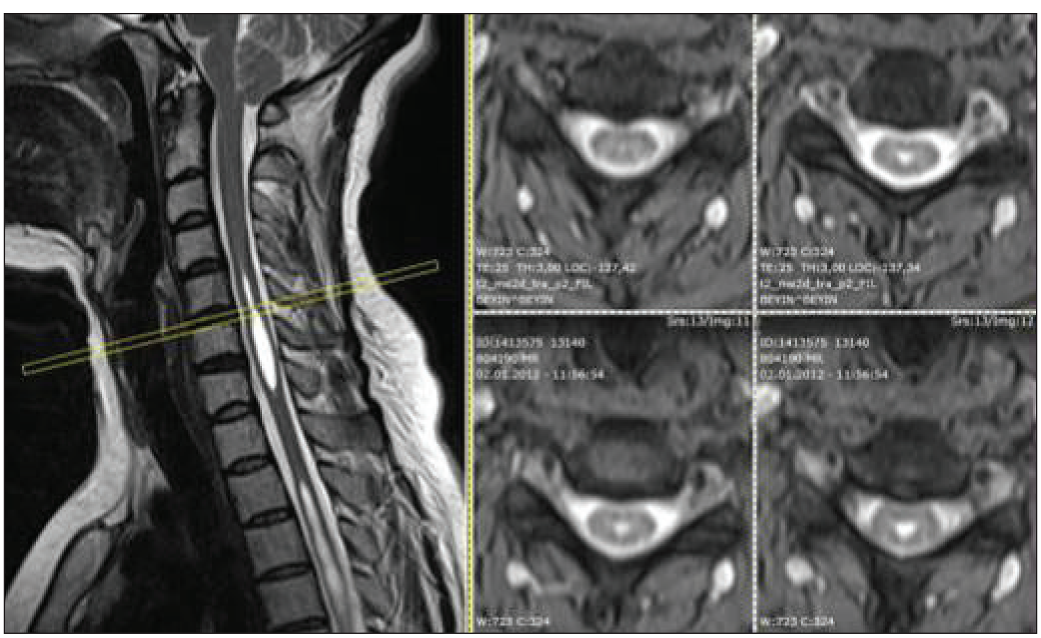

Figure 1: Preoperative MRI imaging of patient with syringomyelia-related CM1.

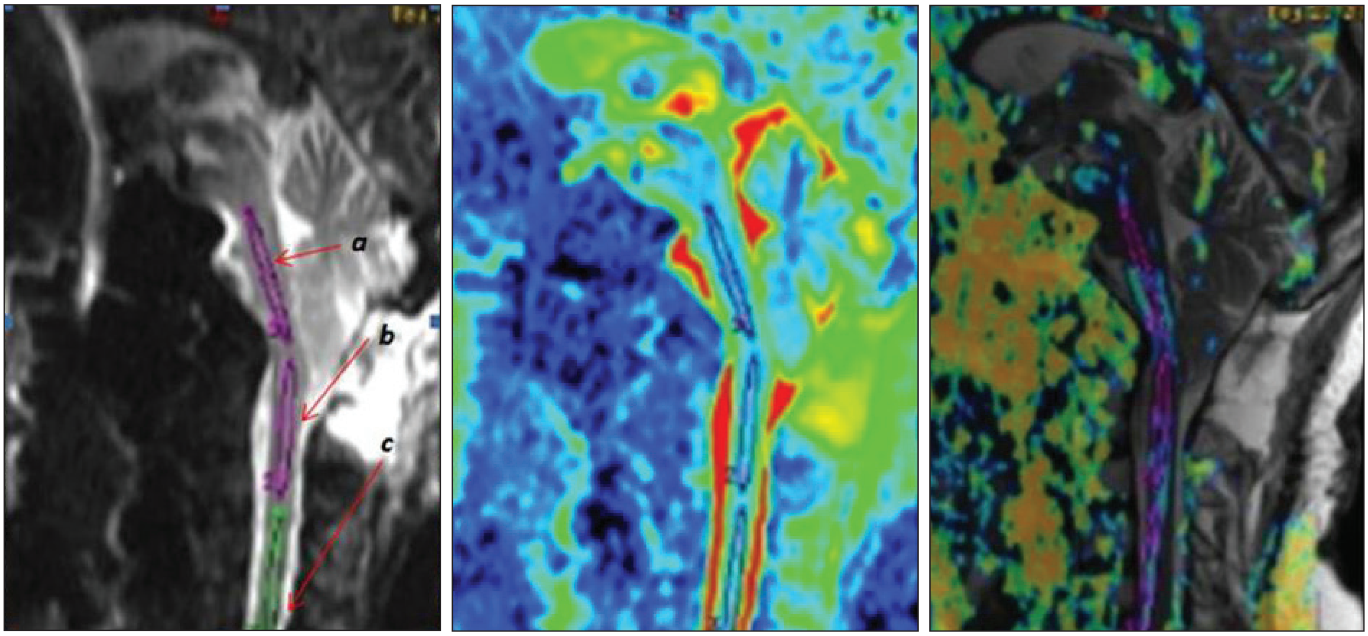

Figure 2: DTI and tractography imaging of a patient with CM1.

Table II: Chicago Chiari Outcome Scale (CCOS)

Pain	Non-pain	Functionality	Complications	Total Score
1: Preoperative symptoms worse	1: Preoperative symptoms worse	1: Unable to attend	1: Persistent complication-poorly controlled	4: Incapacitated outcome
2: Unchanged/refractory to meds/onset of new managed symptoms	2: Unchanged/refractory to meds/onset of new managed symptoms	2: Moderate impairment (<50% attendance)	2: Persistent complication-well controlled	8: Impaired outcome
3: Improved/ managedwith meds/ onset of new symptoms managed with meds	3: Improved-unimpaired/ onset of new symptoms managed with meds	3: Mild impairment (>50% attendance)	3: Transient complication	12: Functional outcome
4: Resolved/no onset of new symptoms	4: Resolved/no onset of new symptoms	4: Fully functional	4: Uncomplicated course	16: Excellent outcome

Table III: Asgari Scale (Clinical Evaluation Scoring)

Observation	Score
Cranial Nerve Involvement	2
Signs of spinal disease, but no difficulty with arms or walking	1
Slight difficulty using arms/hands or walking; can work full-time	2
Moderate disability with arms/hands	2
Complete disability with arms/hands	3
Difficulty walking; prevents full-time employment	3
Need assistance to walk	4
Chairbound or bedridden	5

Table IV: Preoperative Symptoms and Signs of All CM1 Patients

Symptoms	Patients, n (%)	Signs	Patients, n (%)
Headache	30 (90)	Dysesthesia	10 (30)
Neck pain	30 (90)	Loss of sensation	9 (27)
Arm pain	27 (82)	Cerebellar signs	8 (24)
Heat loss of sensation	10 (30)	Hyperactive reflexes of the upper extremity	8 (24)
Numbness in the extremities	9 (27)	Hyperactive reflexes in lower limb	7 (21)
Diplopia	9 (27)	Lower cranial nerve involvement	2 (6)
Leg pain	4 (12)	Babinski signs	2 (6)
Tinnitus	4 (12)	Loss of strength in the lower extremities	2 (6)
Limb weakness	3 (9)	Nystagmus	1 (3)
Dysphasia	1 (3)	Loss of strength in the upper extremities	1 (3)

Marked neck pain was observed in the early postoperative period that gradually decreased over time, especially toward the sixth postoperative month. Patients who complained of only pain and numbness preoperatively showed excellent improvement. Partial improvement was observed regarding dysesthetic complaints, especially of hands and arms, as well as other non-localizing symptoms, such as dizziness, visual symptoms, sleep problems, coughing fits.

The pain was completely resolved in 24 patients, whereas it was mild to moderate enough to be tolerated using simple analgesics in 9 patients. Furthermore, in 17 patients, symptoms unrelated to pain were completely resolved. On the other hand, neuropathic symptoms in 11 patients, and other symptoms unrelated to pain in 5 patients partly persisted. In 2 patients, the moderate activity limitation observed during the preoperative period decreased after surgery. No surgical complications were observed in any patient. According to CCOS, 30 patients scored 13 or higher, whereas 3 scored 9–12. Notably, none of the patients scored 8 or less.

According to the Asgari scale, the symptoms were slight in 15 patients, moderate in 15 patients, and severe in 3 patients preoperatively. At the sixth postoperative month, 14 patients had no symptoms, 15 had slight symptoms, 3 had moderate symptoms, and 1 patient had severe symptoms. Upon evaluation of patients' symptom severity based on the Asgari scale, a difference of 2 or more points was observed between the scores of the preoperative and sixth postoperative month in 27 patients. Notably, this points difference was less than 2 in six patients. Consequently, based on this scale, clinical improvement was observed in 27 patients.

Radiological Results

Postoperative MRI scans revealed normalization of the subarachnoid spaces, which appeared to be tight preoperatively, especially at the cervicomedullary region. Patients with syringomyelia demonstrated clinical improvement. Although no radiological improvement was observed in the size of the syrinx cavities during the early postoperative period, a partial regression was reported in the sixth postoperative month (Figure 3).

During the preoperative assessment, no differences were observed between Group-A and Group-B regarding ADC values obtained from the "a" and "b" regions, but a statistically significant differences were observed in values obtained from the "c" region ($p<0.05$). In addition, no differences were observed between Group-A and Group-B regarding the FA values obtained from the "c" region, but statistically significant differences were observed in values obtained from the "a" and "b" regions ($p<0.05$) (Table V).

Furthermore, no differences were observed between Group-A and Group-C regarding ADC values obtained from the "a" and "c" regions, but values obtained from "b" region exhibited a statistically significant difference ($p<0.05$). Similarly, no differences were observed between Group-A and Group-C regarding FA values obtained from the "a" and "c" regions ($p>0.05$), but values obtained from the "b" region showed a statistically significant difference ($p<0.05$) (Table V).

During the postoperative assessment, no differences were noted between Group-A and Group-B regarding ADC values obtained from the "a" region, but statistically significant differences were observed for values obtained from the "b" and "c" regions ($p<0.05$). Moreover, no differences were observed between Group-A and Group-B regarding FA values obtained from the "a" and "c" regions, but a statistically significant difference was noted for values obtained from the "b" region ($p < 0.05$) (Table V).

No differences were noted between Group-A and Group-C regarding ADC values obtained from the "a" and "c" regions, whereas a statistically significant difference was observed in values obtained from the "b" region ($p<0.05$). In addition, no differences were observed between Group-A and Group-C regarding FA values obtained from the "a" and "c" regions, but a statistically significant difference was noted for values obtained from the "b" region ($p<0.05$) (Table V).

Figure 3: Partial regression of syrinx cavity observed at the end of the sixth month.

Table V: Mean DTI and Tractography Values of Groups

	FA			ADC		
	a	b	c	a	b	c
Group-A	0.406 ± 0.03	0.568 ± 0.07	0.521 ± 0.06	0.815 ± 0.05	1.049 ± 0.15	1.169 ± 0.16
Group-B Preoperative	0.475 ± 0.05	0.474 ± 0.04	0.506 ± 0.06	0.793 ± 0.07	0.920 ± 0.28	0.897 ± 0.21
Group-B Postoperative	0.438 ± 0.05	0.429 ± 0.05	0.511 ± 0.06	0.795 ± 0.07	0.936 ± 0.12	0.930 ± 0.12
Group-C Preoperative	0.454 ± 0.09	0.497 ± 0.06	0.476 ± 0.13	0.780 ± 0.06	0.876 ± 0.09	1.108 ± 0.79
Group-C Postoperative	0.413 ± 0.07	0.466 ± 0.09	0.497 ± 0.16	0.814 ± 0.08	0.879 ± 0.16	0.999 ± 0.79

For Group-B, no differences were observed upon the comparison of pre- and postoperative ADC values of any region. No differences were observed regarding pre- and postoperative FA values obtained from the “c” region ($p>0.05$), but statistically significant differences were detected for values from the “a” and “b” regions (Table V). For Group-C, no differences were observed upon the comparison of pre- and postoperative ADC or FA values from any region (Table V).

DISCUSSION

DTI and tractography studies have been conducted mostly for traumatic spinal cord injury, cervical spondylotic myelopathy (CSM), spinal cord tumors, multiple sclerosis, syringomyelia, transverse myelitis, and CM2, rather than CM1. Currently, this method is commonly used to evaluate the infiltration, destruction, or displacement of the white matter tracts by using fiber tractography (4,5,7,13,25,27,35,36). In acute human spinal cord injury (SCI), DTI shows a reduction in diffusivity, particularly FA and ADC, around the injury site (7,27). Contrarily, in chronic SCI, the injury site is characterized by increased diffusivity. In addition, FA values and connection rates of fiber tracking have been shown to correlate with the motor score in patients with chronic cervical cord injury (5). In patients with CSM, DTI indexes appear to depend on the degree of cord damage. Symptomatic patients have lower FA values and higher ADC measures at the compressed level compared with asymptomatic patients with radiological features of cord compression (13). Measurement of diffusion indexes within the spinal cord tumors suggests that higher tumor mass is characterized by a decrease in FA and an increase in ADC (30).

Therefore, based on this imaging method, it may be possible to view the function of the spinal cord and the properties of signals in the descending and ascending tracts in patients with CM1.

Several surgical treatment methods have been recommended for CM1, some of which are considered to be controversial. Suboccipital craniectomy with concurrent C1 laminectomy is the widely accepted conventional surgical treatment. However, the literature reports no well-established methods that can fully assess the results of decompression, probably because of the limited knowledge regarding the pathophysiology of the disease. Moreover, retrospective studies have not provided enough data to set guidelines that can direct the treatment algorithm. The current data reveals that no link exists between the age and results, and that surgery offers excellent results in patients with mild or moderate neurological deficits. Notably, it was reported that preoperative pathology improves after surgery in more than 83% of patients. The symptoms that mostly show improvement are headache; neck pain; and those related to the cerebellum or brainstem compressions, such as dysphagia, ataxia, nystagmus, and diplopia. Notably, poor outcome is observed in patients with syrinx (33). Nonetheless, these evaluations are subjective, and objective data is required to determine the prognosis. Therefore, based on the imaging method (DTI and tractography), it may be possible to view the function of the spinal cord and the properties of signals in the descending and ascending tracts in patients with CM1.

Milhorat et al. reported that central cord lesions are caused by irreversible damage, and occurs mostly in patients with syringomyelia. Nagib reported that the best improvement after surgery was observed in patients with scoliosis (with an angle of less than 30°), head and neck pain, and sleep apnea (20). Notably, motor and sensory deficits were characterized by the least recovery. In addition, patients with small posterior fossa volume exhibited better recovery than those with normal-sized posterior fossa in their study. On the other hand, even though the results vary depending on the surgical technique applied, symptoms related to syringomyelia, such as pain, scoliosis, and loss of sensation, tend to show less improvement. The lack of a standard outcome measure is one of the major limitations in Chiari research. It has limited the ability to compare the results of various studies. Recently, a group from the University of Chicago has proposed that the Chicago Chiari Outcome Scale (CCOS) is promising as a standard measure for patients with CM1. Moreover, they investigated whether there were any predisposing factors that influenced the postoperative surgical outcome (1).

Asgari et al., defined another scoring system, in addition to the preoperative MRI, which enabled them to evaluate patients on a scale based on the clinical assessment (8). Points were assigned for various neurological impairments and totaled to classify the patient's symptoms as slight (clinical score 1–3), moderate (clinical score 4–6), or severe (clinical score 7–10). All patients underwent decompression surgery, namely suboccipital craniectomy, laminectomy, and duraplasty, and were evaluated using the MRI and the clinical scale postoperatively. The radiological outcome was rated as either sufficient or insufficient decompression, and the clinical improvement was defined as a change in the score by 2 or more points.

Per the CCOS and Asgari scale, the surgical technique that we performed on patients with CM1 was quite successful. The surgical technique that involved posterior fossa decompression without opening the dura mater led to remarkable clinical improvement in patients with CM1. DTI and tractography values of all patients with CM1 were compared with the normal group, and it was observed that FA values at the pontobulbar and C3–4 regions were near normal after surgery in patients with CM1 without syringomyelia. Moreover, FA values at the same locations were near normal in patients with CM1 with syringomyelia. This postoperative "normalization" corroborates the excellent clinical results gauged by CCOS and Asgari scale and suggests that DTI and tractography could be used as valuable tools to predict the prognosis of patients with CM1.

On the other hand, the postoperative FA values at the cervicomedullary region being closer to the isotropic value in all patients with CM1 (with or without syringomyelia) could be probably from the increase in free movement of water molecules in all directions (isotropic diffusion). In addition, it would have been because of the planar anisotropy of water molecules owing to the intersecting complex anatomical structures in this region of the spinal cord.

CONCLUSION

Nonetheless, our limited number of patients and short follow-up period may have prevented us from making a definitive conclusion that DTI and tractography might be an excellent prognostic tool in patients with CM1. Therefore, further randomized controlled trials involving large series of patients and long-term follow-up are needed to adequately determine the prognostic role of DTI and tractography in patients with CM1.

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