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# Diffusion tensor MR imaging in spinal cord injury

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ABSTRACT

*Background:* The ability of diffusion tensor imaging (DTI) to complement conventional MR imaging by diagnosing subtle injuries to the spinal cord is a subject of intense research. We attempted to study change in the DTI indices, namely fractional anisotropy (FA) and mean diffusivity (MD) after traumatic cervical spinal cord injury and compared these with corresponding data from a control group of individuals with no injury. The correlation of these quantitative indices to the neurological profile of the patients was assessed.

*Material and methods:* 20 cases of acute cervical trauma and 30 age and sex matched healthy controls were enrolled. Scoring of extent of clinical severity was done based on the Frankel grading system. MRI was performed on a 3T system. Following the qualitative tractographic evaluation of white matter tracts, quantitative datametrics were calculated.

*Results:* In patients, the Mean FA value at the level of injury (0.43+/−0.08) was less than in controls (0.62+/−0.06), which was statistically significant (p value <0.001). Further, the Mean MD value at the level of injury (1.30+/−0.24) in cases was higher than in controls (1.07+/−0.12, p value <0.001). Statistically significant positive correlation was found between clinical grading (Frankel grade) and FA values at the level of injury (r value = 0.86). Negative correlation was found between clinical grade and Mean MD at the level of injury (r value = −0.38) which was however statistically not significant.

*Conclusion:* Quantitative DTI indices are a useful parameter for detection of spinal cord injury. FA value was significantly decreased while MD value was significantly increased at the level of injury in cases as compared to controls. Further, FA showed significant correlation with clinical grade. DTI could thus serve as a reliable objective imaging tool for assessment of white matter integrity and prognostication of functional outcome.



## Introduction

Spinal trauma can result in devastating medical, social, emotional and financial consequences, especially when associated with neurological damage. Diagnostic imaging plays a crucial role in evaluating and detecting spinal trauma. The imaging assessment of these patients has undergone dramatic changes over the past several years. Today, conventional MR imaging is performed routinely to demonstrate soft tissue and spinal cord injuries in spinal trauma [1–3]. Many advantages of MRI such as higher contrast resolution, absence of bony artifacts, multiplanar capability, and choice of various pulse sequences make it possible to diagnose spinal trauma more accurately. Conventional MRI relies heavily on changes in signal intensity for depiction of pathology. However, the literature is ambivalent about the relationship between MRI findings and extent of neurological damage. According to certain reports, edema and hemorrhage in the spinal cord following trauma are well demonstrated by MR imaging and may help to predict neurologic outcome [4–6]. However, some studies suggest that although spinal cord edema, hemorrhage and interstitial fibrosis will appear as changes in signal intensity on conventional MRI, they may not always be successful in the prediction of functional deficit [7].

Diffusion tensor imaging (DTI) is a novel MR imaging technique which assesses the microstructural integrity of nerve fiber tracts. It is based on the simple principle of diffusion of water molecules in tissue. In neuronal tissue, this mobility is restricted to one particular direction by the presence of biological barriers such as cell membranes and myelin sheath, hence the diffusion is termed anisotropic. Interruption or alteration of this linear molecular diffusion at any point along the neuron can be the first sign of a

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physiological disturbance, which makes DTI more sensitive to early change even before gross structural changes are evident [8]. DTI is currently the only means for non-invasive in vivo assessment of white matter tract integrity [9]. The two most widely used quantitative DTI indices are fractional anisotropy (FA) and mean diffusivity (MD). The ability of DTI to complement conventional MR imaging by diagnosing subtle injuries to the spinal cord in humans, or predict the need for early therapeutic intervention for optimal clinical outcome is a subject of intense research [10]. We hypothesized that there would be changes in DTI indices in spinal cord injury, which could correlate with the ultimate neurological deficit. Our purpose was to study changes in the DTI indices, namely FA and MD in patients with traumatic spinal cord injury and assess the correlation of these quantitative data metrics to the neurological profile of the patients.

## Material and methods

20 cases of cervical trauma, with/without neurologic deficit diagnosed clinically or/and by radiological imaging were recruited for the study from the neurosurgery department of a reputed hospital, within 7 days of sustaining trauma. 30 age and sex matched healthy controls were also included. Written, informed consent was obtained from all subjects. Subjects with concomitant spinal pathology (eg. old Pott's spine) were excluded. Subjects with non MR compatible metallic implants and those with claustrophobia were excluded from the study. The institutional review board approved of the study.

Following a detailed history and clinical examination, radiographs and CT scan were taken where indicated. MRI of cervical spine was performed on a three tesla (3T) MR system (Siemen's Skyra). The MR protocol was as follows: (a) Sagittal T1: repetition time in milliseconds (msec) [TR]/echotime in msec [TE] – 450/9.5, (b) Sagittal T2:TR/TE – 3630/104, (c) Axial T1: TR/TE – 450/9.6 and (d) Axial T2: TR/TE −500/15. For DTI, we used a single shot echo planar imaging (EPI) sequence (b-value = 0,700 s/mm$^2$) using 20 diffusion encoding directions with scan time of approximately 6 min. The image was acquired in axial plane with image matrix of $128 \times 128$, slice thickness of 5 mm with no inter-slice gap, and a field of view (FOV) of $280 \times 280$ mm. To enhance the signal-to-noise ratio and reduce the phase fluctuations, magnitude-constructed images were repeated (averages = 4) and temporally averaged.

Following image acquisition, the data was analyzed quantitatively and qualitatively. For qualitative analysis, a region of interest (ROI) was drawn in the region of the spinal cord. This became a seed-point for the automatic generation of the entire white matter tract in the segment of the spinal cord included in the FOV, by inbuilt software. For evaluation of quantitative indices, an ROI (size 3 mm) was drawn into the white matter column of the spinal cord. Special care was taken to avoid partial volume averaging with underlying grey matter and overlying CSF. By means of the inbuilt software, automatic calculation of DTI indices namely FA and MD was performed within the ROI. These indices were evaluated at the level of injury, and one vertebra above and below the level of injury. In controls we evaluated the FA and MD values at all cervical vertebral levels and individually computed the average FA and average MD in each subject. The patients were reassessed clinically 1–2 months after the DTI study. Scoring of extent of clinical severity was done based on the Frankel grading system – a five point system (A–E in decreasing order of severity), which takes into account the sensory and motor deficit [11].

The data collected was statistically analyzed by SPSS (version-15.0) software. Chi-square test was applied to compare sex distribution between cases and controls. Unpaired *t*-test was applied to compare age of cases and controls. Changes in DTI in the form of fractional anisotropy and mean diffusion were obtained. These changes were statistically compared with age and sex matched controls by unpaired *t*-test. Correlation of DTI changes with clinical severity (based on Frankel grading) was performed using Spearman correlation.

## Results

A total of 20 cases and 30 healthy controls was enrolled. In Case group (n = 20), age range was from 17 to 54 yrs. (Mean age-35.95 ± 10.86 yrs). In Control group (n = 30), age range was from 19 to 54 yrs. (Mean age-35.90+/−10.13 yrs.). The difference in age of Cases and Controls was not statistically significant (p value = 0.802) by Unpaired *t*-test. There were 20 males and 10 females in Control group and 14 males and 6 females in Case group. The difference in distribution based on sex in Cases and Controls was not statistically significant (p value = 0.292) by Chi-square test.

Of the 20 cases of cervical trauma, there was evidence of vertebral fracture in 4, spondylolisthesis in 4, bone-marrow edema in 4, reduced disc height in 4, disc bulge in 9, secondary spinal canal stenosis in 8., cord compression in 10, nerve- root compression in 7, cord signal changes in 10 and hemorrhagic changes in the form of extradural hematoma seen in 1. MR study of controls revealed no significant finding (Table 1). In the study group involving cases of cervical injury (n = 20), the Mean FA value at the level of injury (0.43+/−0.08) was less than the Mean FA value of cervical spine (0.62+/−0.06) in controls (n = 30), which was statistically significant (p value <0.001). However no significant difference was found in Mean FA value above the level of injury or below the level of injury in comparison to controls (Table 2). Further, the Mean MD value at the level of injury (1.30+/−0.24) in cases (n = 20) was higher than the Mean MD value of controls (1.07+/−0.12), which was statistically significant (p value <0.001). However no significant difference was found in Mean MD value above or below the level of injury between Cases and Controls (Table 2). Statistically significant ($p < 0.01$) positive Spearman's correlation

**Table 1**
Conventional MRI findings in cases of injury of cervical spine.

| S. No | MRI findings | No. of Cases of Cervical spine |
|---|---|---|
| 1 | Vertebral fracture | 4 |
| 2 | Spondylolisthesis | 4 |
| 3 | Bone-marrow edema | 4 |
| 4 | Reduced disc height | 10 |
| 5 | Disc bulge | 9 |
| 6 | Secondary spinal canal stenosis | 8 |
| 7 | Cord compression | 10 |
| 8 | Nerve root compression | 7 |
| 9 | Cord signal changes | 10 |
| 10 | Hemorrhagic changes (extradural hematoma) | 1 |