Original Article

Diffusion tensor imaging observation in Pott's spine with or without neurological deficit

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Abstract

Background: Diffusion tensor imaging (DTI) is based upon the phenomenon of water diffusion known as "Brownian motion." DTI can detect changes in compressed spinal cord earlier than magnetic resonance imaging and is more sensitive to subtle pathological changes of the spinal cord. DTI observation in compressed and noncompressed spinal cord in tuberculosis (TB) spine is not described. This study presents observations in Pott's spine patients with or without neural deficit.

Materials and Methods: Thirty consecutive cases of TB spine with mean age of 32.1 years of either sexes with paradiscal lesion, with/without paraplegia divided into two groups: Group A: (n = 15) without paraplegia and group B: (n = 15) with paraplegia were evaluated by DTI. The average fractional anisotropy (FA) and mean diffusivity (MD) values were calculated at 3 different sites, above the lesion (SOL)/normal, at the lesion and below SOL for both groups and mean was compared. Visual impression of tractography was done to document changes in spinal tracts.

Results: The mean canal encroachment in group A was 39.60% and group B 44.4% (insignificant). Group A mean FA values above SOL, at the lesion and below SOL were 0.608 ± 0.09, 0.554 ± 0.14, and 0.501 ± 0.16 respectively. For group B mean FA values above SOL, at the lesion and below SOL were 0.628 ± 0.09, 0.614 ± 0.12 and 0.487 ± 0.15 respectively. There was a significant difference in mean FA above the SOL as compared to the mean FA at and below SOL. P value above versus below the SOL was statistically significant for both groups (0.04), but P value for at versus below the SOL (0.01) was statistically significant only in group B. On tractography, disruption of fiber tract at SOL was found in 14/15 (93.3%) cases of group A and 14/15 cases (93.3%) of group B (6/6 grade 4, 3/3 grade 3 and 5/6 grade 2 paraplegic cases).

Conclusion: The FA and MD above the lesion were same as reported for healthy volunteer hence can be taken as control. FA increases, and MD decreases at SOL in severe grade of paraplegia because of epidural collection while in milder grade, both decrease. In group A (without neurological deficit), mean FA and MD in patients with and without canal encroachment was similar. On tractography, both groups A and B (with or without neurological deficit) showed disruption of fiber tract at SOL and thickness of distally traced spinal cord was appreciably less than the upper cord. FA and MD could not differentiate between various grades of paraplegia. Although the number of patients in each group are small.

Key words: Diffusion tensor imaging, fractional anisotropy, mean diffusivity, tractography, tuberculosis spine, paraplegia, tractography

MeSH terms: Spine, diffusion, tuberculosis, paraplegia

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Access this article online	
Quick Response Code:	Website: www.ijoonline.com
	DOI: 10.4103/0019-5413.156195

Introduction

The diffusion magnetic resonance imaging (MRI) was introduced in the mid-1980s.[1-3] The water molecules due to their thermal energy in body tissue exhibit a random translational moment, termed Brownian motion or diffusion.[4] Which when unrestricted in all directions, is termed as isotropic. In biological tissues (muscle fibers and axons), this mobility is restricted to a particular direction by the biological barriers. Hence, the diffusion is termed anisotropic. Anisotropic diffusion measured for direction and speed, forms the basis of diffusion tensor imaging (DTI). In DTI, any longitudinal structure imaged is broken down into small three-dimensional structures called voxels. The

integrity of long linear structures is tracked by calculating the direction and speed of diffusion occurring in adjacent voxels serially. Alteration or interruption of linear molecular movement (diffusion) at any particular point of the longitudinal structure can be the first sign of a physiological disturbance, which makes DTI more sensitive to early change even before gross structural changes are evident. DTI analyzes the magnitude and orientation of random microscopic motion of water molecules in brain and spinal cord tissue.[5] To provide details on tissue microstructure and organization well beyond the usual image resolution. It is more sensitive to subtle pathological changes of the spinal cord compared to conventional MR.[6] This change is assessed either by "fiber tracking techniques" (tractography) or by calculating DTI anisotropy indices (datametrics).[5]

The neurological complications in tuberculosis (TB) of spine are caused by mechanical pressure on the spinal cord by an abscess, granulation tissue, caseous tissue, tuberculous debris and by mechanical instability produced by pathological dislocation/subluxation.[7] The spinal cord may develop cord edema/myelomalacia/cord atrophy or syringomyelia. The preserved cord volume and cord edema have been correlated with good neural recovery. The myelomalacia, severe cord atrophy and syringomyelia are the poor indicator of neural recovery.

The observations on DTI in spinal TB with/without neural deficit are not described, hence this prospective study on a consecutive series of cases.

Materials and Methods

30 consecutive patients of spinal TB with paradiscal lesion D12-L1 and above, diagnosed clinicoradiologically/on histopathological examination/by molecular methods), with/without paraplegia, of any age attending the orthopedics out patient clinics and indoor of a tertiary care center were included in this prospective study. Informed consent was taken from all patients/family. The study was approved by Institutional ethical committee. The patients were divided into two groups: Group A: (n = 15) spinal TB without paraplegia and group B: (n = 15) spinal TB with paraplegia. Patients who did not have classical clinicoradiological and imaging features of TB spine, known cases of other chronic illnesses, having metallic implants *in situ* (pacemaker) or claustrophobic patients were excluded.

All enrolled patients were documented for history and clinical examination. Neurological deficit was graded by Jain and Sinha scoring.[8] Hemogram/liver function and renal function tests, X-ray chest posteroanterior view and X-ray spine anteroposterior and lateral views were obtained. We looked for demineralization of vertebra, destruction of end plates, fuzziness of paradiscal margins, reduction/obliteration of disc space, wedging of vertebra, obvious kyphotic deformity, paravertebral shadow, anterior scalloping of vertebral body in radiographs of spine. The psoas abscesses when present was aspirated and the material was sent for Z-N staining, pus culture and polymerase chain reaction (PCR).

Pretreatment MRI was done in all patients. The presence of marrow edema of contagious vertebral bodies, preserved disc, pre/paravertebral septate/loculated/subligamentous/epidural collection, epidural spread, end plate erosions and intraosseous abscess was considered diagnostic in TB spine.

Pretreatment DTI was performed at Institute of Nuclear Medicine and Allied Sciences on 3 Tesla Siemens Magnetom Skyra, Malvern, USA (syngo MR D11) system. A total of 25 axial sections at 5 mm thickness was obtained to cover one vertebral segment above and one vertebral segment below the involved segment of the spinal cord with distance factor = 2 mm; field of view = 280 mm × 280 mm; repetition time = 4100 msonds; echo time = 66 msonds; number of excitations (NEX) = 4; fat suppression = spair; matrix = 128 × 128; diffusion directions = 20; b values = 0 and 700. The DTI imaging plane was parallel to the conventional axial images, perpendicular to the long axis of the spinal cord.

Image processing

Quantitative analysis of DTI data was performed using software on a Syngofast Viewer imaging software platform, Erlangen, Germany (siemens Magnetom Skyra). Maps of fractional anisotropy (FA) and mean diffusivity (MD) were generated with background noise suppressed. The regions of interest (ROI) were placed on the spinal cord to include both central gray and white matter with a standard deviation ≤10%. ROI locations were confirmed using the optimal conventional MR imaging sequence, and care was taken to avoid inclusion of CSF. Spinal cord FA and MD values were calculated from the DTI metrics on a voxel-by-voxel basis and displayed as two-dimensional color and gray-scale images by manually drawn ROIs by averaging the 3 ROI (one segment above the involved segment i.e.; the normal cord segment, involved segment and one segment below the involved segment with 3 ROI each) per patient. The size of the ROIs had to be adapted to the axial size of the spinal cord.

All patients in both groups were treated with antituberculous chemotherapy and bed rest. All fresh cases were put on antitubercular therapy regimen as per directly observed treatment strategy (DOTS) category I alternate

day (thrice-weekly doses). Surgical decompression (with or without instrumented stabilization) was done in patients of group B with severe neurological deficits (stage IV or V paraplegia, rapid onset paraplegia), developing/deteriorating new deficits while on treatment, panvertebral disease, severe kyphotic deformity. The tissue was subjected for histopathological examination, pus and granulation tissue for Z-N Staining, tubercular culture and polymerase chain reaction for mycobacterial complex.

The following observations were recorded:

Fractional anisotropy

The mean FA values were calculated above the lesion (normal site), at the lesion and below the lesion for both groups. The mean FA of group A was compared with group B to evaluate any difference between two groups. In both groups, mean FA value above the lesion (taken as control) was compared to the values at and below the lesion. The mean FA of group A patients (n = 10) with canal encroachment on MRI and without neural deficit was compared with without canal encroachment and without neural deficit (n = 5). In group B, 9 patients with a severe paraplegia (stage 4 and stage 5) were compared with 6 patients with mild paraplegia (stage 1 and stage 2 neural deficit). The FA value means (above the lesion, at the lesion and below the lesion) were recorded for all four subgroups and compared.

Mean diffusivity

The same method was applied to document and compare MD values (as was done for FA values) between group A and B.

Tractography

The visual impression of fiber tract was also compared in both groups.

Statistical analysis

The data collected were entered in SPSS (IBM, New York, USA) 17.0 for analysis. Changes in DTI in the form of FA were taken on the scale of 0–1, and that of MD was taken on the scale of 0–2. The demographic characteristics were compared using Chi-square and Student's *t*-test. The mean score of different groups was compared using independent *t*-test and difference in both the scores in a single group was compared using one-way ANOVA with *post-hoc* test (depicting individual *P* value). $P < 0.05$ was considered as statistically significant.

Results

The mean age was 32.1 years (range: 14–70 years) with 18 females and 12 males. All the patients had a history of constitutional symptoms (evening rise of temperature, back pain, loss of weight, and appetite) with mean duration of 6.83 months (group A: 5.73 months, group B: 7.93 months).

In group B, 6 had stage 5 paraplegia, 3 had stage 4 paraplegia and remaining 6 had stage 2 paraplegia. The diagnosis was clinicoradiological (n = 18) with characteristic features on X-ray (97%) and MRI. The diagnosis was ascertained by histopathology (n = 10) PCR and culture while in one patient, aspirate from the soft tissue abscess and in another patient by excision biopsy was subjected positive for AFB smear and PCR. The culture grew no organism in all.

Seventy eight vector borne (VB) were diseased with mean of 2.60 (range 2–6). Twenty seven cases had dorsal spine affect with 2 and one in lumbar and cervical, respectively. Twenty two had 2 VB disease while three had 3 and 5 VB diseased. One each had 4 and 6 VB affection.

Eighteen patients (group A, 6 and group B, 12) had a mean kyphosis of 28.66° (range 15–53°) as measured by modified Konstam angle method.

Magnetic resonance imaging observations

Subligamentous spread was observed in 26 patients (group: A [12] and group: B [14]), epidural spread in 24 patients (9 in group A and 15 in group B). Cord edema was observed in 17 patients (3 in group A and 14 in group B), impingement of cord was observed in 23 patients (8 in group A and 15 in group B), canal encroachment was observed in 25 patients (group A [n = 10] and group B [n = 15]) with mean of 39.60% (range: 10–90%). The mean canal encroachment in group B patients with grade 4 and 3 paraplegia (n = 9) was 44.44% (range 10–90%) and in patients with grade 2 paraplegia (n = 6) was 40% (range 10–80%) which was statistically insignificant (P = 0.59). Cord granuloma was observed in one patient in group B and cord indentation was observed in 23 patients (group A; 8 and group B; 15).

Diffusion tensor imaging parameters

Fractional anisotropy

In group A (n = 15), mean FA value above the site of lesion (SOL) (taken as control) was 0.608 ± 0.09. While at and below the SOL, was 0.554 ± 0.14 and 0.501 ± 0.16 respectively [Table 1]. The difference above the lesion with at SOL was statistically insignificant, while above versus below SOL was significant (P = 0.04) and at versus below SOL was insignificant [Figure 1A-D].

In group B (n = 15), mean FA value above the SOL was 0.628 ± 0.09, at and below the SOL was 0.614 ± 0.12

Table 1: FA values in groups A and B

Groups	Number of patients (*n*)	Average FA value above lesion (mean±SD)	Average FA value at lesion (mean±SD)	Average FA value below lesion (mean±SD)	*P*
Group A	15	0.608±0.09	0.554±0.14	0.501±0.16	Above versus at=0.29 Above versus below=0.04 At versus below 0.31
Group B	15	0.628±0.09	0.614±0.12	0.487±0.15	Above versus at=0.77 Above versus below=0.00 At versus below=0.01
P		0.57	0.23	0.81	

FA=Fractional anisotropy, SD=Standard deviation

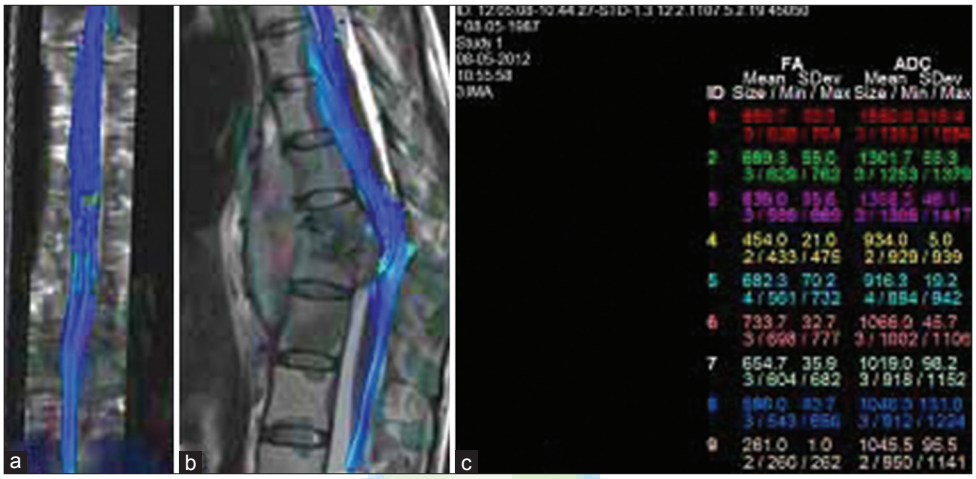

Figure 1A: Tuberculosis spine D9–D10 without neurological defi cit. (a and b) Three-dimensional tractography image acquired in the anteroposterior plane whereas, medio-lateral plane superimposed on sagittal T2 magnetic resonance imaging image shows disrupted fi ber tracts at D7–D8 that is, at the site of lesion (SOL). Thickness at the SOL and distally traced spinal cord tracts was appreciably less than the upper spinal cord. (c) Fractional anisotropy and mean diffusivity or ADC values generated on 3 Tesla Siemens Magnetom Skyra (syngo MR D11) system. No. 1, 2, 3 region of interests (ROIs) above the SOL (control). No. 4, 5, 6-ROIs at the SOL, No. 7, 8, 9-ROIs below the SOL

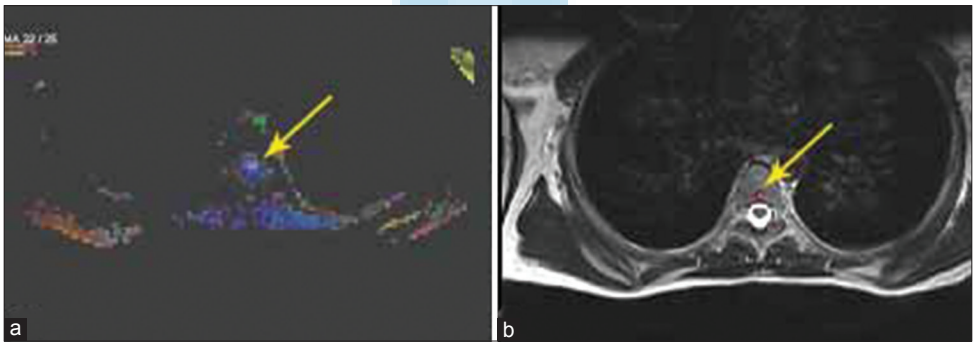

Figure 1B: Method of placing region of interests (ROIs) for measuring fractional anisotropy (FA) and mean diffusivity (MD) values. (a) Once the axial diffusion tensor imaging images were acquired, FA and MD values were acquired by drawing circular ROIs in the axial FA maps. These ROIs were drawn including both the grey and white matters of the spinal cord. 3 ROIs at serial intervals (yellow arrow) drawn above the site of lesion (control). (b) Corresponding axial T2 magnetic resonance imaging shows no compression of the spinal cord

and 0.487 ± 0.15, respectively. The difference in above versus at SOL was insignificant, above versus below the SOL was significant ($P = 0.00$) and at versus below the SOL was significant ($P = 0.01$) [Figures 2-4].

In group A, patients with canal encroachment ($n = 10$), mean FA values above, at, and below the lesion were 0.587 ± 0.09, 0.575 ± 0.14, and 0.466 ± 0.18, respectively, While in patients without canal encroachment ($n = 5$), the FA values above, at and below the lesion were 0.649 ± 0.07, 0.510 ± 0.17, and 0.571 ± 0.12 and the difference was statistically insignificant. Thus, mean FA value in group A was similar in those with canal encroachment and without canal encroachment.

In group B, patients with severe paraplegia ($n = 9$), mean FA value above, at, and below the SOL were 0.620 ± 0.09, 0.673 ± 0.05, and 0.578 ± 0.10, respectively. The FA value

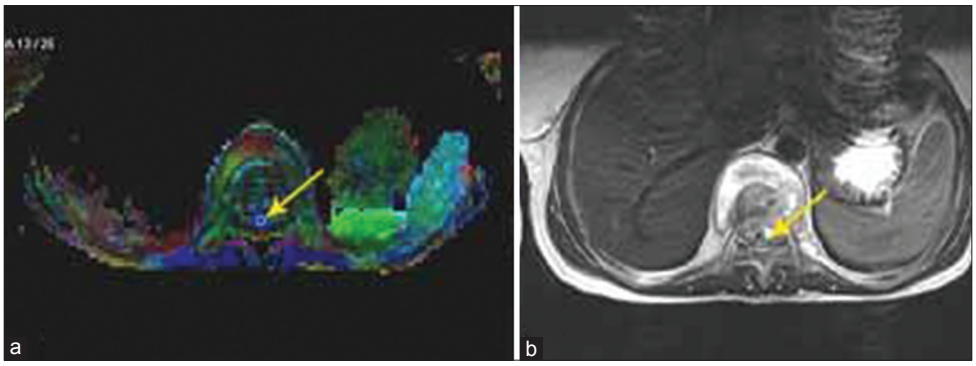

Figure 1C: (a) Region of interests at serial intervals (yellow arrow) drawn at the site of lesion. (b) corresponding axial T2 magnetic resonance imaging shows prevertebral and epidural collection

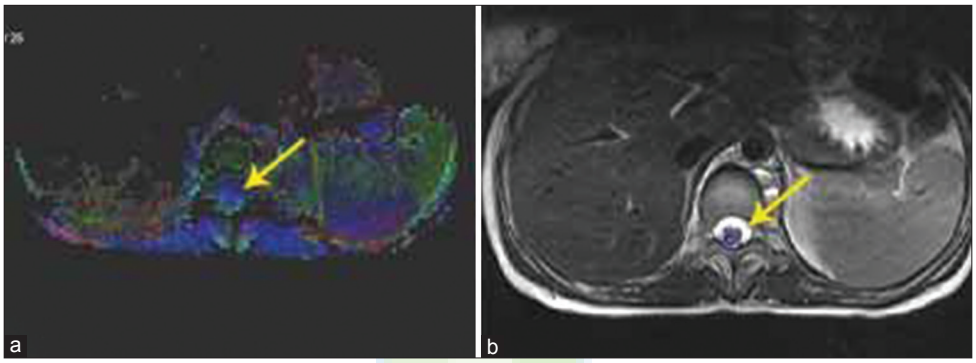

Figure 1D: (a) Region of interests at serial intervals (yellow arrow) drawn below the site of lesion. (b) Corresponding axial T2 magnetic resonance imaging shows no epidural collection

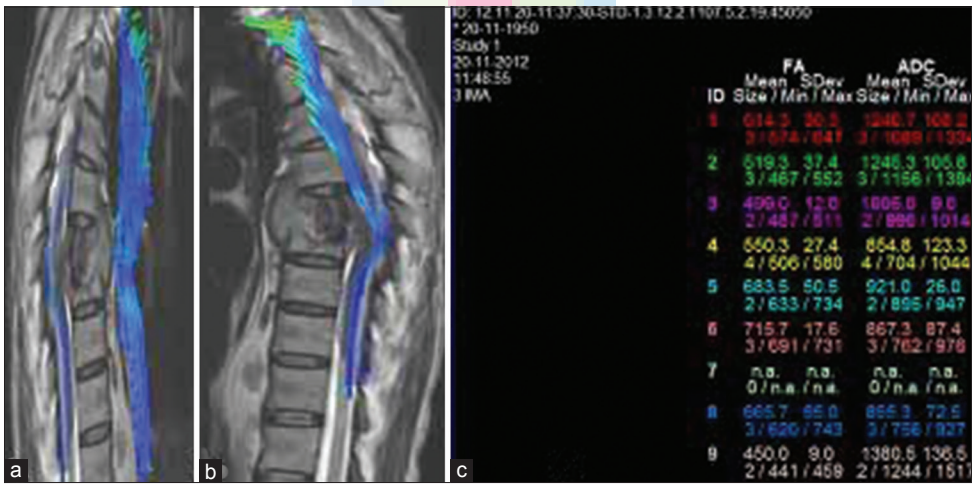

Figure 2: Tuberculosis spine D7–D8 with Grade 4 paraplegia (a and b) Three-dimensional tractography image acquired in the antero-posterior plane whereas, medio-lateral plane superimposed on sagittal T2 magnetic resonance imaging image shows disrupted fiber tracts at D7-D8 i.e., at the site of lesion (SOL). Thickness at the SOL and distally traced spinal cord tracts was appreciably less than the upper spinal cord. (c) Fractional anisotropy and mean diffusivity or ADC values generated on 3 Tesla Siemens Magnetom Skyra (syngo MR D11) system. No. 1, 2, 3-region of interests (ROIs) above the SOL (control). No. 4, 5, 6-ROIs at the SOL, No. 7, 8, 9-ROIs below the SOL

above versus at the SOL and above versus below were insignificant but at versus below the SOL was significant ($P = 0.03$).

In group B, patients with mild paraplegia ($n = 6$), mean FA value above, at, and below the SOL were 0.639 ± 0.11, 0.526 ± 0.15, and 0.349 ± 0.12, respectively. P values were significant at all sites (above vs. at = 0.03, above vs. below ≤0.001 and at vs. below = 0.02).

Within group B, the mean FA values above, at and below SOL were compared between patients of severe ($n = 9$) and mild ($n = 6$) paraplegia [Table 2]. There was marginal difference (statistically insignificant) in the mean FA value of

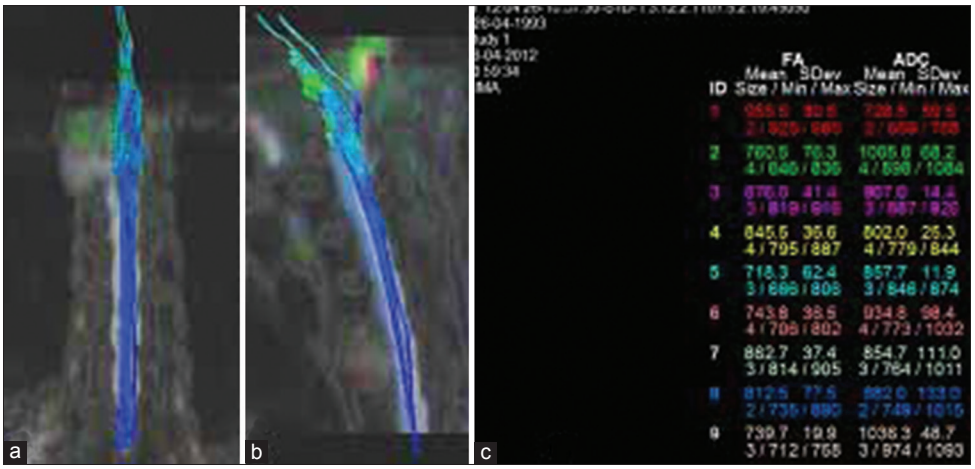

Figure 3: Tuberculosis Spine D3–D4 with Grade 3 Paraplegia (a and b) Three-dimensional tractography image acquired in the antero-posterior and medio-lateral plane show disrupted fiber tracts at the site of lesion (SOL) and below it. Thickness at the SOL and distally traced spinal cord tracts was appreciably less than the upper spinal cord. (c) Fractional anisotropy and mean diffusivity or ADC values generated on 3 Tesla Siemens Magnetom Skyra (syngo MR D11) system. No. 1, 2, 3-ROIs above the site of lesion (SOL) (control). No. 4, 5, 6-ROIs at the SOL, No. 7, 8, 9-ROIs below the SOL

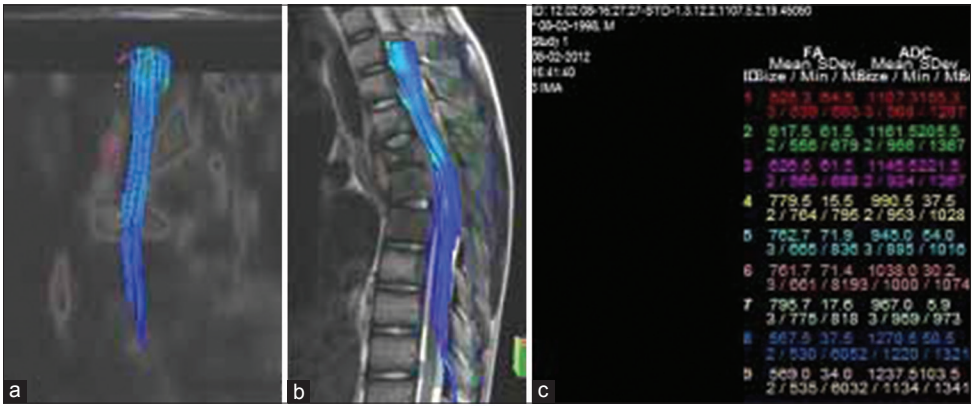

Figure 4: Tuberculosis spine D5–D6 with grade 2 paraplegia (a and b) Three-dimensional tractography image acquired in the antero-posterior plane whereas, medio-lateral plane superimposed on sagittal T2 magnetic resonance imaging image shows disrupted fiber tracts at D5-D6 and below it. Thickness at the site of lesion (SOL) and distally traced spinal cord tracts was appreciably less than the upper spinal cord. (c) Fractional anisotropy and mean diffusivity or ADC values generated on 3 Tesla Siemens Magnet-om Skyra (syngo MR D11) system. No. 1, 2, 3-region of interests (ROIs) above the SOL (control). No. 4, 5, 6-ROIs at the SOL, No. 7, 8, 9-ROIs below the SOL

mild and severe paraplegic patients above the lesion but at and below the SOL there was gross reduction in the mean FA values in milder neural deficit in comparison to severe deficit. The *P* value for this difference at and below the SOL was significant (0.01, <0.001, respectively).

Mean diffusivity

The average MD values were calculated at 3 different sites, above, at, and below the lesion for both groups A and B [Table 3].

In the group A, the difference in the mean MD values for above versus at, at versus below and above versus below SOL were statistically insignificant.

In group B, a minor difference (statistically insignificant) in the mean MD value for above versus at and above versus below was observed. However, there was no difference in the mean MD values for at versus below the SOL.

The mean MD value in group A, for patients with canal encroachment (n = 10), above, at and below the lesion were 1.518 + 0.31, 1.229 + 0.27, and 1.595 + 0.54, respectively. There were (statistically insignificant) differences in the mean MD values, when compared for above versus at, at versus below and above versus below the SOL.

In group A, patients without canal encroachment (n = 5), the mean MD value means above, at and below the lesion were 1.290 ± 0.19, 1.643 ± 0.62 and 1.380 ± 0.38 respectively. The differences, when compared for above versus at, at versus below and above versus below the SOL were statistically insignificant. Within the group A,

the mean MD values above, at and below SOL were compared between patients without (n = 10) and with canal encroachment (n = 5). However, these differences were statistically insignificant.

Group B patients with a severe paraplegia (n = 9), the mean MD values for above versus at and at versus below SOL were statistically significant [Table 4]. However, the difference in the mean MD values for above versus below was statistically insignificant. Within group B patients with mild paraplegia (n = 6), the mean MD values for above versus at and above versus below SOL were statistically insignificant; however, there was no difference for at versus below SOL.

Tractography

In the group A (n = 15), 14 patients had disrupted fiber tract at the SOL while one had continuous fiber tract. Thicknesses of the distally traced spinal cord tracts were appreciably less than the upper spinal cord in 13 patients. While in 2 patients, thicknesses were same [Figure 1].

In group B (n = 15), 6 patients with stage 5 paraplegia, had disrupted fiber tract at the SOL. The thickness of the distally traced spinal cord tracts was appreciably less than the upper spinal cord in 4 patients while there was abrupt cessation of fiber tracts below lesion in 2 [Figure 2].

All patients with stage 4 paraplegia (n = 3) had disrupted fiber tract at the SOL and thickness of the distally traced spinal cord tracts were appreciably less than the upper spinal cord [Figure 3]. In patients with stage 2 paraplegia (n = 6), 5 patients had disrupted fiber tract at the SOL and thickness of the distally traced spinal cord tracts was appreciably less than the upper spinal cord, while in one there was no disrupted fiber tract at the SOL and thickness of the distally traced spinal cord tracts was same as the upper spinal cord [Figure 4]. Hence, it appears that the tractography does not appear to correlate well with the clinical grade/severity of paraplegia.

Discussion

Diffusion tensor imaging is known to be more sensitive to

Table 2: FA values of patients of severe and mild paraplegia

Types of paraplegia	Average FA value above lesion (mean±SD)	Average FA value at lesion (mean±SD)	Average FA value below lesion (mean±SD)	*P*
Severe paraplegia (*n*=9)	0.620±0.09	0.673±0.05	0.578±0.10	Above versus at=0.21 Above versus below=0.31 At versus below=0.03
Mild paraplegia (*n*=6)	0.639±0.11	0.526±0.15	0.349±0.12	Above versus at=0.03 Above versus below=0.00 At versus below=0.02
P	0.73	0.01	<0.001	

FA=Fractional anisotropy, SD=Standard deviation

Table 3: MD values in group A and B

Groups	Number of patients (*n*)	Average MD value above lesion (mean±SD)	Average MD value at lesion (mean±SD)	Average MD value below lesion (mean±SD)	*P*
Group A	15	1.442±0.29	1.367±0.44	1.523±0.49	Above versus at=0.62 Above versus below=0.59 At versus below=0.31
Group B	15	1.299±0.29	1.144±0.39	1.312±0.31	Above versus at=0.21 Above versus below=0.91 At versus below=0.18
P		0.19	0.16	0.17	

MD=Mean diffusivity, SD=Standard deviation

Table 4: MD values of patients of severe and mild paraplegia

Types of paraplegia	Average MD value above lesion (mean±SD)	Average MD value at lesion (mean±SD)	Average MD value below lesion (mean±SD)	*P*
Severe paraplegia (*n*=9)	1.247±0.23	1.003±0.13	1.322±0.29	Above versus at=0.03 Above versus below=0.50 At versus below=0.00
Mild paraplegia (*n*=6)	1.375±0.38	1.356±0.56	1.298±0.36	Above versus at=0.49 Above versus below=0.89 At versus below=0.57
P	0.43	0.09	0.89	

MD=Mean diffusivity, SD=Standard deviation

subtle pathological changes of the spinal cord compared to conventional MR,[7] because FA/MD values and fiber tracking contain more and complementary, information about the microstructure of white and grey matter than the conventional imaging contrasts. The spinal cord signal intensity changes on MRI sequences are of limited value for predicting functional outcome. Although DTI of the spinal cord is currently only a research tool, however, preliminary studies suggest it of considerable promise in predicting the severity of spinal cord injury.[9]

Diffusion tensor imaging have shown changes in the integrity of spinal cord and provided complementary information to MRI in cervical spondylosis,[10] multiple sclerosis,[11] chronic cord compression,[12] myelitis,[13] and spinal cord tumours.[14] It is more sensitive than T2-weighted imaging in patients with cervical myelopathy.[12]

Diffusion tensor imaging parameters are sensitive markers of cervical cord injury and MD shows the greatest sensitivity than FA.[15] Changes in DTI parameters are most marked at injury sites and reflect the severity of cord injury. Rajasekaran *et al*.[16] reported the use of DTI in demonstrating the changes seen in posttraumatic Brown–Sequard syndrome and found that the FA and MD values show significant changes at the level of injury. They opined that the identification of undamaged fibers in patients with a spinal cord injury may help the surgeon predict their neurological recovery.[16]

Tuberculosis spine is a slowly developing treatable disease, and if adequately treated, the neurology could be reversible. The evaluation of spinal cord changes on DTI may allow us to anticipate the developing neural deficit. Since no observations exist on DTI in TB spine, hence this is the initial observation of DTI in TB of spine with or without paraplegia, so that future studies on diagnostic and prognostic value of DTI observation in varying severity of TB paraplegia can be defined.

The DTI observations at disease level required a comparison from normal spinal cord. Hence, one segment above the lesion was taken as control. Healthy volunteers were taken as control in various articles published so far.[10,12-15,17-26] Range of average FA and MD values for all healthy volunteers in these studies was 0.40–0.85 and 0.70–1.50, respectively. These FA and MD values were comparable to the FA and MD values of our control groups. There was no significant difference in the mean FA and MD values between controls of both group A and B. Range of average FA values in group A was 0.413–0.729 and in group B was 0.451–0.863 and range of average MD values in group A was 1.084–1.889 and in group B was 0.88–1.947, for control. These ranges matched with healthy volunteers taken in previous studies. Hence, FA/MD value one segment above the compressed spinal cord can be taken as control.

Fractional anisotropy values

The mean FA value decreases at SOL in comparison to control in both groups, but the decrease was minor in group B. The FA values of both the groups (A and B) decrease below the SOL when compared to control (above SOL). The FA value decreases below the SOL when compared with FA value at SOL in both the groups, but the decrease was significant in group B (with paraplegia) only.

In the study conducted by Chang *et al*.[20] (n = 10) with chronic cervical spinal cord injury (>1-month postinjury), it was seen that the FA value decreases significantly in the patients when compared to control (healthy volunteer). However, this study does not mention about FA value below the SOL. Ducreux *et al*.[14] studied 5 patients with spinal cord Astrocytomas with spastic paraparesis (n = 2 with solid mass tumor and n = 3 with cysts around the masses). It was seen that FA values decreased in both the solid mass group and cystic tumor groups suggestive of either local extracellular edema or decreased number of fibers increasing the extracellular space, or both. Renoux *et al*.[13] studied 15 patients with symptomatic myelitis (multiple sclerosis (60%), neurosarcoidosis (20%), transverse myelitis (13%), polyradiculoneuritis (7%) and 11 healthy volunteers. They found that all abnormal areas seen on T2-weighted imaging had a significantly decreased FA value. In 9 patients (60%) the FA value was found to be decreased in the presence of normal T2-weighted imaging and these areas matched with the level of neural deficit in 1/3 of the cases. Five patients (33%), 3 with multiple sclerosis, 1 with polyradiculoneuritis and 1 with sarcoidosis had increased FA values in normal T2 weighted areas.

The data in TB are different than quoted above, as the compression is mechanical which may be liquid, solid (dry) or mixed along with inflammatory edema. While all above studies were a solid/cystic affects of spinal cord. The implication may not be a true compares ion.

Patients with canal encroachment and those without canal encroachment were compared with each other, mean FA value *at* and *below* SOL decreased (statistically insignificant) in both as compared to control. Lee *et al*.[24] conducted a study in 20 patients of cervical compressive myelopathy and found that the FA values decreased for the most severe compression levels. Mamata *et al*.[10] studied 11 healthy volunteers and 79 patients of cervical spondylosis. They found that 54% of patients showed decreased FA at stenotic spinal canal level compared with the normal spinal cord, 46% showed no decrease in FA value of spinal cord at the narrowed spinal canal level. However, the articles cited

above have not described whether patients in their study were paraplegic or nonparaplegic.

The patients with a severe paraplegia and those with mild paraplegia were compared with each other. In patients with a severe paraplegia, the mean FA value showed an increase at the SOL when compared with control whereas in the mild paraplegic patients the mean FA value decreased. In both groups, (severe and mild paraplegic patients) mean FA value below SOL decreased as compared to control, but the difference was significant only in the mild paraplegic group. The FA value increase at the SOL in patients with a severe paraplegia is because, with higher grade of neural deficit, there is significant cord compression by the epidural collection. While placing the region of interest, the voxel showing the inflammatory tissues were also included. The inflammation and organized fibrin tissue does not allow free water diffusion. However water is flowing along the cell membrane of inflammatory cells and organized fibrin is present in the epidural collection. There are no supportive data on DTI of spinal cord comparing acute or chronic infective compression but a study by Gupta *et al*.[27] on 8 patients with brain abscess (BA) the wall and cavity of the abscess were assessed with DTI and found that the FA significantly increased in the BA wall compared to BA cavity.

In a patient with mild paraplegia, mean FA value at and below SOL decreased as compared with control (significant) and also below SOL was significantly reduced when compared *at* SOL. Spinal cord distal to compression was showed reduced FA values most likely due to wallerian degeneration as also explained by Kamble *et al*.[23] on 29 patients of spinal cord injury following road traffic accident (3–84 months post-trauma). They performed DTI in the cervical region if cord myelomalacia or signal changes were present in the dorsal cord/conus region and vice versa. They found significantly reduced FA in the cord either above or below the site of injury, although routine imaging did not show any signal changes. They also found reduced FA value in the lower cord if the injury was in the cervical region and reduced FA value in the cervical region if the injury was in lower cord. They concluded that there is associated ascending and descending wallerian degeneration which can be detected by tensor imaging.

Mean diffusivity values

In both the groups (A and B), the mean MD values were decreased at SOL and increased below SOL as compared to the control (insignificant). In both the groups, the mean MD value increased insignificantly below SOL when compared to *at* SOL. Chang *et al*.[20] (n = 10) with chronic cervical spinal cord injury (>1-month post injury), noted statistically significant difference in the MD values between patients and control. In the group A (without paraplegia), MD value was higher at the SOL when compared with group B (with paraplegia).

The patients with and without canal encroachment were compared with each other. The mean MD value at SOL showed an insignificant decrease in patients with canal encroachment and insignificant increases in patients without canal encroachment as compared to control. In both these groups, the mean MD value below the SOL increased insignificantly as compared to control. In patients with canal encroachment, the mean MD value below the SOL increased insignificantly when compared with at SOL, whereas in patients without canal encroachment, the mean MD value decreased insignificantly as we moved from at SOL to below SOL. In a study by Lee *et al*.,[24] the MD value increased at the most severe compression levels in cervical compressive myelopathy patients. Mamata *et al*.[10] 54% of patients showed increased MD at stenotic spinal canal level compared with the normal spinal cord, 46% showed no elevation in MD value of spinal cord at the narrowed spinal canal level. However, the articles cited above have not mentioned whether patients in their study were paraplegic or nonparaplegic.

The mean MD values of patients with severe and mild paraplegia were compared. Both severe and mild paraplegic patients showed a decreased *at* SOL as compared to control, however, in the mild paraplegic patients, this decreased in mean MD value was insignificant. These observations correspond with the result of the study by Gupta *et al*.[27] which showed decreased in MD value in the BA wall compared to BA cavity. The mean MD value increased insignificantly *below* the SOL when compared to control in patients with a severe paraplegia, whereas it decreased insignificantly in patients with mild paraplegia. The mean MD value in patients with a severe paraplegia increased significantly below SOL as compared to at SOL, whereas it decreased insignificantly in patients with mild paraplegia.

Tractography

The disruption of fiber tract at the SOL was found in 14/15 of both groups. Thickness of distally traced spinal cord tracts was appreciably less than the upper spinal cord in 13/15 (83.3%) cases of group A and 12/15 (80%) cases of group B (4/6 stage 5, 3/3 stage 4 and 5/6 stage 2 paraplegic cases), whereas thickness of distally traced spinal cord tracts were same as upper spinal cord in 2/15 (13.3%) cases of group A and 1/6 (16.6%) stage 2 paraplegic case in group B. In 2/6 (33.3%) stage 5 paraplegic cases, there was abrupt cessation of fiber tracts below lesion. Till date, no data on tractography of TB spine is available. Diffusion tensor tractography was done by Rajasekaran *et al*.[16] in the case of 30-year-old male with partially injured spinal cord tracts diagnosed as posttraumatic Brown–Sequard syndrome. They found that at injury zone, there was abrupt cessation

of fiber tracts on the left side of the thoracic spinal cord whereas the long tracts could be traced normally on the right side below injury. Thickness of distally traced spinal cord tracts was appreciably less than the upper spinal cord. However, individual tracts could not be traced. The observation of posttraumatic Brown–Sequard syndrome cannot be compared with a tubercular situation as there is a mechanical severance of hemispinal cord in the reported case. However, our study, revealed similar tractographic result in nonparaplegic, mild and severe paraplegic patients. Hence, we concluded that the tractography study has limited value for the clinicians in TB spine.

Conclusion

Diffusion tensor imaging observation one segment above the SOL could be used as control in spinal TB. In paraplegic patients, FA value did not decrease significantly at the site of compression because of epidural collection. The MD decreased at the SOL as the inflammatory cells and organized fibrin prevented free water diffusion thus maintaining a high anisotropy levels. Significant decrease in FA below the site of epidural compression was noted most likely as a result of wallerian degeneration which was supported by increased MD values. Insignificant changes in FA and MD were noted in patients who had MR based cord compression but no clinical neural deficit. This was probably because the compressive effect of the epidural collection was not sufficient to disturb the integrity of the neural tracts. FA and MD values could not differentiate between various stages of paraplegia because the number of cases in each group of paraplegia was less. Hence, studies with a larger sample size to relate the FA and MD values with the stages of paraplegia are required.

The tractography reduction in the tract size observations does not correlate well with the absence/presence of severity of paraplegia.

Acknowledgment

We acknowledge Dr. R. P. Tripathi, MD, Scientist 'H', Institute of Nuclear Medicine and Allied Sciences Delhi - 110 054 for granting permission to conduct the study at their institute.

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How to cite this article: Abbas S, Jain AK, Saini NS, Kumar S, Mukunth R, Kumar J, *et al.* Diffusion tensor imaging observation in Pott's spine with or without neurological deficit. Indian J Orthop 2015;49:289-99.

Source of Support: Nil, **Conflict of Interest:** None.