Diffusion tensor imaging of spinal cord as an emerging tool in neuroradiology!!!

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Learning objectives

Learning objectives:

1. To evaluate the definitive changes occurring in neural elements as seen on Diffusion tensor imaging in various spinal cord pathologies (traumatic and non-traumatic) at the site of injury as well as normal appearing cord proximal and distal to the site of injury.
2. To collect data that can help us understand these microstructural changes within the cord and assist in prognostication and planning of therapies.

Background

Background:

Spinal cord damage leads to the major functional impairments and disability. So if the structural integrity of the cord is assessed in symptomatic patients at the earliest then it may help in better prognosis.

Diffusion tensor imaging (DTI) is one of the magnetic resonance imaging (MRI) technique that is useful for the measurement of magnitude and direction of the diffusion of water molecules in neural tissues thus providing insight into the internal structural abnormalities and their severity. The measurement of DTI indexes provides a quantitative assessment of neural damage in various myelopathies.

Principles of DTI:

The diffusion of water molecules in nervous system is predominantly parallel to axon fibers and this direction dependent diffusion is described as anisotropy. [1, 2, 3] This is used by DTI to delineate orientation and anatomy of axon fibers in nervous system to build a tensor framework by using molecular motion in multiple directions in 3 dimensional planes. Accordingly DTI indexes are calculated using diffusivities along 3 principle axes and commonly used indexes are fractional anisotropy (FA) and Mean diffusivity (MD).

Fractional anisotropy is the magnitude of anisotropy or directionality of diffusion process of water molecules in tissues. It ranges from 0 to 1. Zero value means complete isotropy and no restriction as we get in free water. Value of 1 means diffusion completely restricted in one particular direction.
Mean diffusivity is the measure of the average molecular displacement independent of any tissue directionality. As MD value increases the isotropy of the tissue also proportionately increases. [4]

Findings and procedure details

Procedure details:

DTI was performed on 1.5T GE MRI machine by applying multiple gradients. Sagittal T2 weighted image was obtained followed by DTI sequence which is a sagittal spin-echo single shot echo planar parallel Grappa diffusion-weighted imaging sequence. We used acceleration factor of 2 and 25 non collinear gradient directions were applied with 2 b values (b = 0 and 500 seconds/mm$^2$).

Then FA and MD indexes were calculated using regions of interest in spinal cord at the site of lesion and also remote from the lesion. We also created 3D white matter fiber tracts by using software which gives visual idea of the fiber anatomy and displacement or destruction.

FINDINGS:

DTI shows definite changes in both traumatic and non-traumatic cord pathologies. Interestingly, changes in DTI indices are visualized in regions of the cord, which appear normal on conventional MRI and are remote from the site of cord compression.

We have evaluated few number of cases of spinal cord DTI over a period of last 6 months. The common cases included spondylosis, TB and trauma in our setting in Indian population. Spinal cord tumors are quite rare and unfortunately we could find only one in this period.

The most common indication for spinal imaging is the pain and/ or neurological symptoms like weakness or tingling, numbness. In few of these patients we have tried DTI imaging and have reached to a conclusion that in early spondylosis DTI makes an important contribution to the patient’s outcome as on conventional MRI there is no abnormality in the cord but only few bony degenerative changes were noted. However when we performed DTI in these patients, we could say that there are microstructural alteration already started in the cord leading to degeneration due to altered canal dimensions or direct indentation on the cord by the osteophytes or disc bulges.
These alterations were picked up on FA and MD values. As the degeneration starts the diffusivity increases due to weakening of cell membranes and we get reduction in FA and increase in MD values. More the severity of cord degeneration more will be the changes in FA and MD values. These values also provide severity grading and help in prognostication of the disease process.

In compressive myelopathies due to neoplasms, if there is only displacement of the fibers without destruction then FA value increases and MD value decreases due to crowding and increased density. This can be taken as good prognostic sign for guiding surgery and can be used for follow up as well in post-operative period.

**CASE 1 Early spondylosis**

A 60 years old man came with complaints of neck pain and mild weakness in both upper limbs with occasional tingling since few months.

T2 weighted sagittal image shows mild changes of spondylosis in the form of marginal osteophytes and mild disc bulges at C3-4, C4-5 and C5-6 levels that indent ventral subarachnoid space. However there is no abnormal signal noted in the cord. DTI performed in the same patient shows decreased FA with corresponding increase in MD values at C4, C5 and C6 levels indicating cord degeneration (Table 1) (Figure 1 & 2).

**TABLE 1**

<table>
<thead>
<tr>
<th>ROI</th>
<th>FA</th>
<th>MD</th>
<th>ROI</th>
<th>FA</th>
<th>MD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVJ</td>
<td>0.564</td>
<td>783</td>
<td>CVJ</td>
<td>0.685</td>
<td>854</td>
</tr>
<tr>
<td>C2</td>
<td>0.665</td>
<td>747</td>
<td>C2-3</td>
<td>0.544</td>
<td>810</td>
</tr>
<tr>
<td>C3</td>
<td>0.651</td>
<td>886</td>
<td>C3-4</td>
<td>0.352</td>
<td>961</td>
</tr>
<tr>
<td>C4</td>
<td>0.431</td>
<td>1062</td>
<td>C4-5</td>
<td>0.343</td>
<td>1163</td>
</tr>
<tr>
<td>C5</td>
<td>0.469</td>
<td>1097</td>
<td>C5-6</td>
<td>0.256</td>
<td>892</td>
</tr>
<tr>
<td>C6</td>
<td>0.274</td>
<td>947</td>
<td>C6-7</td>
<td>0.143</td>
<td>873</td>
</tr>
</tbody>
</table>

Thus based on DTI changes in this case, early conservative action can be taken to halt the disease process and complications of surgical intervention needed in late spondylotic cases can be avoided. Furthermore DTI also shows that the cord changes are more severe at C6, C5 and C4 mid vertebral levels and at C3-4, C4-5, C5-6 and C6-7 disc levels. It helps in exact localization of the neural deficit and gives more specific rather than generalized details of cord degeneration.
CASE 2 Late spondylosis

In this second case cord changes are obvious on conventional MRI. But DTI gives us extent of degeneration and location wise severity grading of the same. Thus a more specific estimation of the most affected spinal cord level can be reported to ease planning of intervention if needed. FA value measurement can also be used for prognostication and follow up to assess the treatment response. (Figure 3) (Table 2)

TABLE 2

<table>
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<tr>
<th>ROI</th>
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</thead>
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<tr>
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<tr>
<td>2</td>
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<td>3</td>
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<tr>
<td>5</td>
<td>0.327</td>
<td>1711</td>
</tr>
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</table>

Case 3 Partially treated case of tuberculosis of dorsal spine

A 35 year old man came with bilateral lower limb weakness since 7 months. He was on treatment for tuberculosis since 5 months. Initially there was complete paralysis to begin with and there is only minimal improvement even after 5 months of treatment. Repeat MRI with DTI was advised to look for the cord status.

MRI shows altered marrow signals in D11 and D12 vertebral bodies and focal T2 hyperintense signal in cord at the same level with associated volume loss suggesting myelomalacia. On DTI images there is approximately 80-90 % loss of fibers with markedly reduced FA value. (Figure 4) (Table 3)

TABLE 3

<table>
<thead>
<tr>
<th>ROI</th>
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<tr>
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<td>0.444</td>
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In this case, DTI results point towards the poor prognosis and incomplete recovery of neurological deficit after treatment. So patient can be acknowledged before only about his prognosis in such cases to build up his mental strength at the beginning only and also avoid any legal complications.

**Case 4 Post traumatic cord injury**

A 32 years old man came with complaints of both lower limb weakness following a road traffic accident few days back. He underwent spinal surgery for vertebral fractures.

T2 weighted sagittal images of the dorsal cord show axial fracture of D12 vertebral body with mild compression of the thecal sac and resultant T2 hyperintense signal within cord probably edema. To know the exact status of the cord injury we performed DTI on him. (Figure 5) (Table 4)

DTI images show a significant disruption of the fiber tracts with markedly reduced FA value and corresponding increase in MD value indicating need for early management. This gives us a rough idea about the severity of injury as well as help in prognostication. DTI can then be followed up in recovery phase to assess the fiber regenerating process and treatment response.

**TABLE 4**

<table>
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<th>ROI</th>
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<tr>
<td>3</td>
<td>0.128</td>
<td>833</td>
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</tbody>
</table>

**Case 5 Extra axial Neurofibroma**

A 26 years old man presented with tingling and numbness and weakness in both upper limbs (left >right) since few months. Symptoms were gradually increasing in severity as per his history. Cervical spinal radiograph was done and there was widening of the neural foramen noted at C4-5 level on left side. Patient underwent MRI for further evaluation. MRI revealed a well-defined bilobed T2 hyperintense lesion at the left C4-5
neural foramen causing its widening. The lesion has extradural extension into the spinal canal and causes moderate to severe compression of the spinal cord which is pushed to right side of the canal. (Figure 6)

We also performed DTI on him and we could see on fiber tractography that the lesion causes displacement and crowding of the fibers at C4-5 level to the right side. There is also increase in FA value noted at this level suggesting increased density of the fibers especially on right side. (Table 5) (Figure 7, 8)

**TABLE 5**

<table>
<thead>
<tr>
<th>ROI</th>
<th>FA</th>
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</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td>0.734</td>
<td>248</td>
</tr>
<tr>
<td>3</td>
<td>0.567</td>
<td>1231</td>
</tr>
</tbody>
</table>

Increased FA value with reduced MD value and displacement rather than destruction of fibers provides a safe surgical margin and also suggests that better prognosis and recovery of the patient can be expected.

**LIMITATIONS:**

The most important limitation we are facing in spinal cord DTI remains the inadequate spatial resolution predominantly in lower thoracic region. The disturbing factors include cardiac and respiratory movements and cerebral spinal fluid (CSF) pulsation artifacts. These can be overcome to some extent by using parallel imaging or gating techniques. [4, 5, 6]

Another limitation is time consumption especially in acute spinal cord injury patients. In these patients signal to noise ratio will also be affected and can cause overestimation of FA values leading to false reports.

Artifacts created by metallic orthopedic hardware in post-operative patients is another major issue to be resolved.

**Images for this section:**
Fig. 1: a) T2 Sag, b,c) Sag FA maps (colored and grey scale) and d) DWI images in a case of early spondylosis

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Fig. 2: Fiber tractography image of the same patient as figure 1.

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Fig. 3: Sag T2 and FA maps show cord changes at C3-4 level with reduced FA value in a case of late spondylosis

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Fig. 4: Case of partially treated tuberculosis of dorsal spine: T2 Sag and DTI with tractography show focal myelomalacia at D11-12 level with significant loss of fibers and markedly reduced FA value.

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**Fig. 5:** Post traumatic case of spinal cord injury. T2 Sag and DTI with fiber tractography images show moderate to severe degree of fiber destruction and cord edema.

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**Fig. 6:** A case of neurofibroma at C4-5 level involving left neural foramen.

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**Fig. 7:** Axial FA map image shows increased FA value more on right side at the level of left sided neurofibroma causing cord compression.

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**Fig. 8:** In the same case of neurofibroma, DTI and Fiber tacrography images show focal smooth displacement of the fibers by the mass (arrow in C)

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Conclusion

1. Thus, in this preliminary study we are trying to make use of DTI a new advanced technique in MRI as an emerging tool for better delineation of spinal cord internal derangements in degenerative, infective, neoplastic and traumatic cases.

2. DTI of the spinal cord helps to guide therapy by early diagnosis and can be used for follow up in recovery stage as its indices will give quantitative assessment along with conventional MRI.

3. In early spondylosis and cord compression by neoplasms or other lesions, DTI has great impact in predicting the treatment response and prognosis as it detects the changes which are not visible on conventional MRI. Thus it has high sensitivity over conventional MRI images.

4. Further advances in its technique in near future would definitely reduce the limitations we are facing today so DTI can be considered as a promising tool in neuroradiology imaging.

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References

References:


