Original Article

Role Of Diffusion Tensor Imaging And Diffusion Tensor Tractography On 3t Mri In Spinal Cord Lesions

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Abstract

AIM: The aim of the study is to study the role of Diffusion Tensor Imaging and Diffusion Tensor Tractography on 3T MRI in spinal cord pathologies.
MATERIAL & METHODS: A Prospective observational study includes 50 students at Padmashree Dr. D. Y. Patil Medical College and Hospital and Research Centre, Pimpri, over the period of 2 years in between September 2020 to November 2022. Patients with suspected spinal cord pathologies were subjected to MR Imaging of the spinal cord. Standard spine protocol (Sag T2 tse, Sag T1 tse, Cor T2 stir, Ax T2 tse, Ax T1 tse), DTI and DTT were done for all patients.
RESULTS: Out of 50 participants 23 were females (46%) and 27 were males (54%) & majority of the patient belonged to age group of 31-40 years (26%). 13 patients were normal, and 9 patients had minimal disc bulges but no significant spinal canal stenosis/ indentation of the spinal cord. These 22 patients considered normal showed mean FA (0.69 +/- 0.01) and ADC values (0.88 +/- 0.09) which were similar at all disc levels. In the 15 patients showing significant spinal stenosis and normal appearing cord, statistically significant reduction in FA values and increase in ADC values were seen at levels C3-C4, C4-C5, C5-C6. 2 patients with syrinx, 2 patients with Hirayama disease, and 2 patients with long and short segment cord hyperintensity had significantly reduced FA and increased ADC values. DTT showed displacement of the white matter tracts ventrally in a case of spinomedullary junction astrocytoma.
CONCLUSION: DTI is a promising new tool which offers an insight on the pathophysiology and microstructural changes related to diseases of the spinal cord. DTI changes appear in normal appearing spinal cord in cases of cervical spondylotic myelopathy. This shows promise in detection, prognosticating and planning treatment in some neurosurgical disorders like CSM. More information is needed regarding the precision and dependability of DTI indices in classifying cord disease. To overcome limitations improvement and standardization of scanning procedures and image processing is necessary.

KEYWORDS: MRI, spinal cord lesions, Diffusion Tensor Imaging, Diffusion Tensor Tractography

INTRODUCTION

The spinal cord is present in the spinal canal extending from the medulla at the foramen magnum and terminates between L1 and L2 usually, where it forms the conus medullaris in the lumbosacral region. Then the nerve roots arising from the lower cord segments form a vertical sheaf called cauda equina. [1]

Most common cause of spinal cord myelopathy is extrinsic compression caused by spinal canal stenosis by herniated disc. Spinal injuries can result due to trauma. Post-operative complications after spine surgery can occur either by compression by hematoma or due to post op infections.

Disorders intrinsic to the cord, such as demyelination disorders like Neuromyelitis optica (NMO), Acute disseminated encephalomyelitis (ADEM), Multiple sclerosis (MS), transverse myelitis & Metabolic conditions like Vitamin B12 deficiency, copper deficiency result in subacute combined degeneration. Infections like epidural abscesses, suppurative leptomeningitis, are also routinely encountered. Common neoplastic conditions of the spinal cord are astrocytomas, ependymomas, and meningiomas [2]

Currently, MRI is the method of choice for assessing the contents of the spinal canal. Sagittal and axial T1- and T2-weighted sequences without fat saturation make up the standard spinal MRI protocols. Diffusion-weighted MR imaging in particular can discriminate between epidermoids and arachnoid cysts A 3D fast spin echo (FSE) sequence variant was introduced more recently. Flip angle modulation during the FSE readout, a characteristic of these imaging sequences, produces high resolution 3D volumetric images that can be reconstructed into several planes. These sequences have been used to evaluate conditions like scoliosis, nerve root compression by herniated disc material, nerve root avulsions, posttraumatic pseudomeningoceles because of their capabilities.

MRI has a well-established role in the evaluation of the acutely injured spine, helping to determine ligamentous disruption, vertebral injury, disc protrusion and the location of the maximum canal stenosis and the kind of cord injury. It may play a greater role in determining early management as new potential strategies in spinal cord injury (SCI) therapy emerge.[3] The condition of the underlying cortical and cancellous bone, musculoskeletal tissues, and intervertebral disc, the location and integrity of surgical implants, the evaluation of the effectiveness of decompression procedures, the delineation of fusion status, and the identification of complications are a few critical points that can be identified using imaging of the postoperative spine. [4]

The white matter of the brain contains the defining lesions of demyelinating illness. On T2WI alone, it might be challenging to distinguish clearly between demyelination and other pathological characteristics linked to demyelinating disease (such as edema, inflammation, remyelination, and axonal loss), as well as to other disorders (e.g. infection, neoplasm etc.). In viral infections, lesions of the spinal cord have varied enhancement and are T2 hyperintense which typically involve the anterior cord and might be solitary, multiple, unilateral, or bilateral. MRI can be used to find new viral lesions and differentiate from other disorders like multiple sclerosis.

Thus, this study aimed to explain the role of Diffusion Tensor Imaging and Diffusion Tensor Tractography on 3T MRI in spinal cord lesions.

MATERIALS AND METHODS

A Prospective observational study includes 50 students at Padmashree Dr. D. Y. Patil Medical College and Hospital and Research Centre, Pimpri, over the period of 2 years in between September 2020 to November 2022. Subject would be defined as any patient coming to the Department of Radio-diagnosis and having been suspect/ proven for spinal cord pathologies. Institutional Ethical Committee (IEC) clearance will be obtained before the start of the study. Informed consent and written consent will be obtained from all the patients.

INCLUSION CRITERIA

- Patients more than 12yrs of age will be included.
- All patients who are referred to the Radio-diagnosis department for MRI of the spine with suspected cord pathologies and few normal patients to act as control group.

EXCLUSION CRITERIA

- Postoperative presence of incompatible orthopaedic hardware.
- Postoperative patients of spinal orthopedic implant less than 1 month after the procedure.
- Patient having history of cardiac pacemakers, metallic foreign body, biostimulators, neurostimulators and cochlear implants in-situ.

METHODOLOGY

All patients compliant with the inclusion and exclusion criteria will be subjected to MR Imaging of the spinal cord.

Standard spine protocol (Sag t2 tse, Sag t1 tse, Cor t2 stir, Ax t2 tse, Ax t1 tse), DTI and DTT, and other sequences relevant to specific cases are done.

MRI SCAN TECHNIQUE

MRI examination will be performed using Siemens Magnetom Vida Magnetic Resonance Imaging 3 Tesla using body array coil and 32 channel spine coil. The MRI Protocol would include the following:

DTI MR IMAGING PROTOCOL

VIEW	Sagittal
TR (REPETITION TIME)	2400 ms
TE (ECHO TIME) 5 ECHOES	55, 88 ms
FIELD OF VIEW	240 x 240 mm^2
MATRIX	130 x 130
FLIP ANGLE	180 o
SLICE THICKNESS	3 mm
BANDWIDTH	962 Hz/pixel
DIFFUSION VALUE	0, 1000
TENSOR DIRECTIONS	12
COIL	Body array
SPINE COIL	32 channel

RESULTS

Age& Gender distribution: Out of 50 participants 23 were females (46%) and 27 were males (54%). 12% belonged to age group of 21-30 years, 26% belonged to age group of 31-40 years, 22% belonged to age group of 41-50 years, 20% belonged to age group of 51-60 years, 16% belonged to age group of 61-70 years, 4% belonged to age group of 71-80 years.

Table 1: Age and Gender wise Distribution

GENDER	**MALE**	**FEMALE**
	27 (54%)	23 (46%)
Age distribution	21-30	6 (12%)
	31-40	13 (26%)
	41-50	11 (22%)
	51-60	10 (20%)
	61-70	8 (16%)
	71-80	2 (4%)

A final diagnosis was reached based on clinical history, and conventional imaging as is tabulated below as table 2. 13 patients were normal, and 9 patients had minimal disc bulges but no significant spinal canal stenosis/ indentation of the spinal cord. For purpose of this study these 22 patients were considered as normal group.

Table 2: Distribution of participants based on diagnosis on conventional MRI imaging:

Diagnosis on conventional imaging	Number
Normal	**13**
Minimal Disc bulge without spinal canal stenosis	**9**
Mild	**8**
Moderate	**5**
Severe	**2**
Disc bulge with compressive myelopathy	**3**
Syrinx	**2**
Hirayama disease with cord hyperintensity and myelomalacia	**2**
Paraverterbal abscess, no intraspinal component	**1**
Long segment cord demyelination	**1**
Short segment demyelination and atrophy	**1**
Spino-meullary junction tumor – astrocytoma	**1**
Cervical subarachnoid cysts with dorsal spine meningitis	**1**
Post-operative with pedicle screws and rods	**1**

Compilation of DTI parameters of normal patients:

Following is the data of FA and ADC values taken at seven levels in the spinal cord ofpatients who had normal findings on conventional MRI.

Table 3: FA and ADC values at various levels in normal patients

Normal						
Levels	Mean FA (SD)	Median	IQR	Mean ADC (SD)	Median	IQR
C1-C2	0.68 (0.01)	0.685	0.680 - 0.689	0.88 (0.10)	0.86	0.80 - 0.90
C2-C3	0.69 (0.01)	0.6855	0.682 - 0.689	0.89 (0.08)	0.879	0.81-0.93
C3-C4	0.69 (0.01)	0.688	0.683 - 0.689	0.86 (0.10)	0.8205	0.78- 0.90
C4-C5	0.70 (0.01)	0.697	0.688-0.701	0.83 (0.09)	0.856	0.76- 0.88
C5-C6	0.69 (0.01)	0.695	0.688- 0.695	0.89 (0.08)	0.856	0.86- 0.98
C6-C7	0.69 (0.01)	0.689	0.687 - 0.695	0.91 (0.07)	0.8975	0.89- 0.99
C7-T1	0.69 (0.007)	0.696	0.691-0.699	0.89 (0.11)	0.866	0.80- 1.00

Table 4: Categories based on spinal canal stenosis

Disc bulge with spinal canal stenosis	
Severity	Number of patients
Normal	22
Mild	8
Moderate	5
Severe	2
Not applicable	13

In the following table mean and median FA values at each disc level of 37 patients including normal and patients with spinal canal stenosis has been tabulated as table 5:

Table 5: FA values

C1-C2 severity category		Normal	Mild	Moderate	Severe	NA
	Mean(SD)	0.68 (0.01)	0.68 (0.008)	0.69 (0.01)	0.68 (0.01)	0.64 (0.08)
	Median	0.685	0.678	0.688	0.679	0.678
	IQR	0.680 - 0.689	0.676 - 0.684	0.685- 0.688	0.671 - 0.686	0.667 - 0.688
C2-C3 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.69 (0.01)	0.69 (0.01)	0.74 (0.09)	0.68 (0.01)	0.65 (0.10)
	Median	0.6855	0.693	0.698	0.683	0.687
	IQR	0.682-0.689	0.689-0.699	0.688-0.708	0.679-0.687	0.672-0.701
	Kruskal wallis H=7.91 ,df= 4 , p=0.10					
C3-C4 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.69 (0.01)	0.69 (0.01)	0.68 (0.02)	0.63 (0.06)	0.64 (0.10)
	Median	0.688	0.684	0.688	0.631	0.688
	IQR	0.683-0.689	0.681-0.694	0.683-0.693	0.588-0.674	0.609-0.691
	Kruskal wallis H= 4.45 ,df=4 , p=0.35					
C4-C5 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.70 (0.01)	0.67 (0.02)	0.64 (0.06)	0.54 (0.20)	0.60 (0.14)
	Median	0.697	0.689	0.673	0.535	0.645
	IQR	0.688-0.701	0.679-0.696	0.591-0.675	0.392-0.678	0.468-0.687
	Kruskal wallis H= 9.40 ,df= 4 , p= 0.05					
C5-C6 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.69 (0.01)	0.64 (0.06)	0.53 (0.11)	0.39 (0.01)	0.56 (0.12)
	Median	0.695	0.6485	0.546	0.387	0.5205
	IQR	0.688-0.695	0.582-0.687	0.456-0.555	0.379-0.395	0.488-0.676
	Kruskal wallis H=22.59 ,df= 4 , p < 0.001					
C6-C7 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.69 (0.01)	0.69 (0.05)	0.60 (0.13)	0.62 (0.06)	0.59 (0.11)
	Median	0.689	0.703	0.679	0.623	0.620
	IQR	0.687-0.695	0.695-0.710	0.454-0.688	0.578-0.669	0.504-0.682
	Kruskal wallis H= 17.26 ,df=4 , p= 0.002					
C7-T1 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.69 (0.007)	0.70 (0.01)	0.69 (0.003)	0.69 (0.001)	0.63 (0.12)
	Median	0.696	0.694	0.694	0.687	0.683

	IQR	0.691-0.699	0.694-0.704	0.694-0.696	0.687-0.688	0.667-0.696
	Kruskal wallis H= 9.40 ,df= 4 , p= 0.05					

In the following table mean and median ADC values at each disc level has been tabulated.

Table 6: ADC values

C1-C2 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.88	1.03	1.00	0.98	0.96
	Median	0.86	1.1	1.1	0.98	0.94
	IQR	0.80-0.90	0.94-1.11	0.88-1.11	0.86-1.10	0.88-0.99
C2-C3 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.89	0.93	0.95	0.92	1.01
	Median	0.87	0.93	0.93	0.92	0.91
	IQR	0.81-0.93	0.91-0.95	0.93-0.96	0.921-0.923	0.85-1.01
	Kruskal wallis H= 4.74, df= 4, p= 0.31					
C3-C4 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.86	0.94	0.92	1.23	1.06
	Median	0.82	0.93	0.94	1.23	0.91
	IQR	0.78-0.90	0.90-0.95	0.95-0.96	0.98-1.5	0.88-1.28
	Kruskal wallis H=11.06 , df= 4 , p= 0.03					
C4-C5 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.83	0.90	1.09	1.38	1.16
	Median	0.856	0.911	0.967	1.378	1.059
	IQR	0.76-0.88	0.85-0.97	0.96-1.2	0.96-1.80	0.91-1.31`
	Kruskal wallis H=21.66 , df= 4 , p<0.001					
C5-C6 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.89	1.19	1.44	1.77	1.24
	Median	0.856	1.063	1.526	1.773	1.223
	IQR	0.86-0.98	0.95-1.45	1.46-1.62	1.70-1.86	0.86-1.60
	Kruskal wallis H= 18.02, df=4 , p= 0.001					
C6-C7 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.91	0.96	1.27	1.15	1.12
	Median	0.897	0.845	0.889	1.148	1.065
	IQR	0.89-0.99	0.79-0.96	0.79-1.89	0.92-1.38	0.91-1.17
	Kruskal wallis H= 6.88, df=4 , p= 0.14					
C7-T1 severity category		Normal	Mild	Moderate	Severe	NA
	Mean (SD)	0.89	0.90	0.88	0.87	0.99
	Median	0.866	0.893	0.893	0.868	0.911
	IQR	0.80-1.00	0.86-0.89	0.89-0.89	0.86-0.88	0.89-0.99
	Kruskal wallis H=3.99, df= 4, p= 0.41					

Table 7: Number of patients with spinal canal stenosis at different levels

Number of patients with disc bulges			
Levels	Mild	Moderate	Severe
C1-C2	0	0	0

C2-C3	0	0	0
C3-C4	2	1	0
C4-C5	5	1	1
C5-C6	9	3	2
C6-C7	3	2	0
C7-T1	0	0	0

Statistically significant reduction in FA values were seen at levels C3-C4, C4-C5,C5-C6. Statistically significant increase in ADC values were seen at levels C3-C4, C4-C5,C5-C6. In the following table mean FA and ADC values at each disc level has been tabulated as table 8

Table 8: Table showing number of levels showing various pathologies and their mean FA and ADC values

Parameters		
PATHOLOGY	Number of levels assessed	Mean (SD)
Normal		
FA	154	0.685 (0.008)
ADC	154	0.878 (0.091)
Disc bulge with compressive myelopathy		
FA	4	0.4325 (0.07)
ADC	4	1.475 (0.16)
Syrinx		
FA	5	0.5446 (0.03)
ADC	5	1.1286 (0.07)
C1 assimilation with C2 invagination + Syrinx		
FA	1	0.584
ADC	1	1.115
Hirayama disease with cord hyperintensity and myelomalacia		
FA	3	0.489 (0.06)
ADC	3	1.622 (0.38)
Paraverterbal abscess, no intraspinal component		
FA	2	0.68 (0.002)
ADC	2	0.853 (0.002)

Long segment cord demyelination		
FA	7	0.392 (0.1)
ADC	7	1.37 (1.36)
Short segment demyelination and atrophy		
FA	1	0.367
ADC	1	1.918
Spino-meullary junction tumor - astrocytoma		
FA	1	0.551
ADC	1	1.229
Cervical subarachnoid cysts with dorsal spine meningitis		
FA	1	0.582
ADC	1	1.252
Post-operative with pedicle screws and rods		
FA	3	Artifacts
ADC	3	Artifacts

DISCUSSION

Spinal cord pathologies cause significant morbidity to patients and Conventional MRI imaging of the spinal cord is routinely performed for their detection. It has been extremely useful in diagnosis, and management of patients. This necessitates the need for newer imaging sequence that could bridge the gap by showing changes that could correlate with the clinical findings and aid in detection, and management of the patients.

In this study we have included 50 patients who came to MRI department with a suspected cervical spinal cord pathology. Based on conventional MRI findings they werecategorized as normal, and into different pathological groups. DTI parameters, FA and ADC values were taken at seven cervical intervertebral disc levels. Of the 50 patients, 13 were normal and 9 had minimal disc bulge without significant spinal canal stenosis. These 22 patients were considered as normal on conventional imaging. They showed mean FA (0.69 +/- 0.01) and ADC values (0.88 +/- 0.09) andwere similar at all disc levels.

Degeneration of the spine is the commonest encountered findings in our study participants. Conventional MRI helps us detect spinal canal stenosis. In our study, 18 patients showed significant spinal stenosis. Of these only 3 patients had changes of compressive myelopathy on T2 imaging. Of the other 15 patients with normal appearing cord, 8 had mild spinal canal stenosis, 5 had moderate spinal canal stenosis, and 3 had severe spinal canal stenosis. We found reduction in FA values and an increase in ADC values at levels C3-C4, C4- C5, C5-C6 which was statistically significant in cases with spinal canal stenosis. DTI parameters takenof the spinal cord taken at the level of spinal canal stenosis showed reduced FA and increased ADC values for mild (FA: 0.667 +/- 0.055, ADC: 1.154 +/- 0.323), moderate (FA: 0.497 +/- 0.682, ADC: 1.596 +/- 0.27), and severe stenosis (FA: 0.389 +/- 0.009, ADC: 1.782 +/- 0.84). The 3 patients of cervical spondylotic myelopathy with T2 hyperintense cord signal showed significantly reduced FA and increased ADC values(FA: 0.433 +/- 0.067, ADC: 1.475 +/- 0.161).

In a study conducted with Tallat Ahmed El Hameed Hassan et al. on thirty patients, there was statistically significant reduction in FA in the cord opposite to most affected disc in comparison to normal cord. [5]

Zafer Orkun Toktas et al, conducted a study on patients who showed neurological evidence of cervical spondylotic myelopathy and compared FA and ADC values in nonstenotic and stenotic cervical spinal segments. In the most stenotic segments, significantly lower mean FA value and increased mean ADC value in comparison to non-stenotic segments. They also found a negative correlation between ADC and FA values. [6]

Hatsuho Mamata MD et al, studied the change in FA and ADC values on 11 normal volunteers and 79 patients with cervical spondylosis. They found decreased FA and increased ADC with age in the normal spinal cord. Reduced FA and increased ADC were found in the spinal cord of patients with spondylosis showing clinical symptoms of myelopathy. [7]

Batuhan Kara et al, in 2011 investigated the role of DTI for early detectionof myelopathy in cervical spondylotic cases in 16 participants without hyperintensity in the spinal cord on T2-weighted sequences but with neurological signsof CSM were included in this study & found that at stenotic segments all patients showed DTI parameter changes before they developed T2 hyperintensities on conventional sequences. [8]

Jean-Francois Budzik et al, in 2010 studied the usefulness of DTI in clinical correlation in patients of cervical spondylotic myelopathy included 15 volunteers and 20 symptomatic patients with CSM. They found that some of the patient's clinical scores showed significant correlation with FA values, while high T2 spinal cord signal intensity was not correlated with the clinical assessment. [9]

In our study, 2 patients showed syrinx at 5 levels and had significantly reduced FA and increased ADC values (FA: 0.545 +/- 0.031, ADC: 1.129 +/- 0.074) in comparison to spinal cord at normal levels (FA: 0.685 +/- 0.008, ADC: 0.878 +/- 0.091). One of them showed C1 assimilation and C2 invagination with syrinx at spino-medullary junction andshowed reduced FA and increased ADC values (FA: 0.584, ADC: 1.115).

In our study we had 2 patients of Hirayama disease with cord hyperintensity and myelomalacia, and had reduced FA (FA= 0.489 +/- 0.055) increased ADC (ADC=1.622+/- 0.38).

In our case of paravertebral abscess, there was no intra spinal component and the DTI parameters (FA: 0.68 +/- 0.002, ADC = 0.853 +/- 0.002) showed no significant change. In a known case of neuromyelitis Optica, which had diffused ill-defined long segment abnormal intensity in spinal cord from C1 to D4 levels with mild spinal cord expansion. It showed reduced FA and increased ADC values (FA: 0.392 +/- 0.098, ADC: 1.367 +/- 1.368, $P<0.001$) in comparison to spinal cord at normal levels in control group (FA:0.685 +/- 0.008, ADC: 0.878 +/- 0.091).

There was one patient who showed a short segment T2 hyperintensity at C2 level which showed reduced FA and increased ADC values (FA: 0.367, ADC: 1.918).

S.M.Hesseltine et al, studied the usefulness of diffusion tensor imaging (DTI) in detention and prognosis of patient with relapsing-remitting multiple sclerosis who had normal-appearing spinal cord. 24 patients and 24 normal control subjects underwent Axial DTI. They found that the patients with relapsing-remitting multiple sclerosis demonstrated DTI changes in normal-appearing spinal cord. This could prove useful for detection of occult spinal cord pathology, predicting the clinical course, and monitoring therapeutic effect in multiple sclerosis. [10]

One patient showed a well-defined heterogeneously enhancing lesion in the dorsal aspect of spinomedullary junction - astrocytoma which was causing compression and anterior displacement of the spinal cord. On DTI it showed reduced FA and increased ADCvalues (FA: 0.551, ADC: 1.229). On DTT it showed displacement of the white matter tracts ventrally. Diffusion tensor tractography was helpful in assessing displacement of white matter tracts.

One patient with thoracic myelitis and cervical subarachnoid collection at C6-C7 level showed reduced FA and increased ADC values (FA: 0.582, ADC: 1.252). One postoperative patient with pedicles and rods, showed dense metallic artifacts and DTI parameters could not be taken at these levels. DTI has limited utility in evaluation of post-operative patients due to artifacts.

CONCLUSION

DTI is a promising new tool which offers an insight on the pathophysiology and microstructural changes related to diseases of the spinal cord. As seen in our study DTI changes appear in normal appearing spinal cord in cases of cervical spondylotic myelopathy and help bridge the gap between clinical and neurological findings and imaging appearance. This shows promise in detection, prognosticating and planning treatment in some neurosurgical disorders like CSM. In cord malignancies DTT helps to differentiate the displacement or infiltration

of the white matter tracts, and thus aids in tumor characterization and surgical planning. We can anticipate the adoption of DTI in standard clinical practice, both to prognosticate and monitor patients with spinal cord illness, once these obstacles have been surmounted.

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