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Original Research Article

A Hospital Based Study Depicting the Role of Diffusion Tensor Imaging in Mapping of White Matter Tracts in Relation to Brain Tumor

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Abstract

Aim: The aim of the present study was to demonstrate the role of Diffusion Tensor Imaging in mapping of white matter tracts in relation to brain tumor.

Material & Methods: A Descriptive study including 50 patients in the Department of Radiology with intracranial neoplasms in between the duration of 1 year was conducted. Pre-operative contrast-enhanced magnetic resonance imaging and DTI scans of the patients were taken into consideration. Pre- and post-operative neurological examinations were performed and the outcome was assessed.

Results: The mean age of the patients was 47.3 years (range 23-71 years). In the study most of the patients were in the age group 31 to 40yrs and 51 to 60 years. Among the 50 cases, 38 were men and 12 were women. Among 50 patients, 30 were intra axial lesion and 20 were extra axial lesion. Most of the cases were solid in nature, rest were necrotic, solid and cystic, solid and necrotic and cystic. Majority of the cases were showing mass effect in the form of compression on the ventricular system, effacement of cortical sulci or basal cisterns, midline shift or herniation. White matter pathway involvement was identified in all patients by using anisotropy, color coded DT imaging maps and 3DMR Tractography. Normal white matter pathways demonstrated on DT imaging appeared unaffected in contralateral hemisphere. The WM tracts were color coded in a universal fashion based on their spatial orientation.

Conclusion: DTI provides crucial information regarding the infiltration of the tract and their displaced course due to the tumor. This study indicates that it is a very important tool for the preoperative planning of surgery. The involvement of WM tracts is a strong predictor of the surgical outcome.

Keywords: Diffusion tensor image, intra-axial brain tumor, magnetic resonance image, tractography, white matter tracts

Introduction

Primary and metastatic brain tumors are serious health problems and have some critical challenges in both their diagnosis and treatment. The most common primary brain tumors are meningiomas and glioblastomas in adults, and pilocytic astrocytomas, malignant glioma and embryonal tumors in children. [1] Intra-axial tumors of the brain are one of the most common tumors to be encountered by neurosurgeons. [2] These tumors are frequently located in or close to eloquent areas, including motor and language areas. Surgical resection of such tumors often injures these tracts and produces severe neurologic complications. [3] Preoperative knowledge of relationship of tumor with the tract is of vital importance. [4] Before proper planning of brain surgery, it is very important to avoid several key functional regions of the brain; these include motor, sensory, auditory, language, and vision fields. [5]

The location and functions of the cortex can be deduced from the folding patterns of the cortex but the white matter appears as just a homogenous structure during surgery. Even if we avoid injury to an important cortical area, the patient could lose function if the white matter tract responsible for the function is cut. Therefore, the identification of motor, language, auditory, and visual pathways is very important for brain surgery. [5]

The imaging modality of choice for brain tumor diagnosis is MRI due to its high contrast resolution, and multiplanar, volumetric imaging capability allowing tissue characterization to some extent. [6] Over the following 30 years, there was an explosion of technological and scientific advancement in the field of MRI. Scanners became faster and more sensitive, and MR phenomena that initially created problems and artifacts, soon became the basis for new imaging techniques. [7] It provides detailed anatomic information regarding the anatomic relation of the tumor and affected brain tissue but it cannot give specific information concerning tumoral white matter involvement, which is critical for treatment planning to minimize the injury to eloquent white matter tracts during surgery. [6,8]

A more advanced diffusion-based MRI method, diffusion-tensor imaging (DTI), processes the diffusion information in a tensor model, which describes the magnitude, degree and orientation of diffusion anisotropy, and estimates the white matter connectivity in a 3D model termed MR tractography. [6,8-10]

Until the advent of DTI, the only reliable techniques used to study axonal pathways were invasive procedures that are only feasible in primate or post-mortem human brains. [11,12] The utility of DTI lies in the many types of images that can be calculated from the information contained in the tensor formalism. These maps can provide scalar information regarding the magnitude and spatial anisotropy of diffusion in a tissue, as well as vector maps that describe directionality of diffusion. Hence the aim of study was to demonstrate the role of Diffusion Tensor Imaging in mapping of white matter tracts in relation to brain tumor.

Material & Methods

A Descriptive study including 50 patients in the Department of Radiology, Lord Buddha Koshi Medical College and Hospital, Saharsa Bihar India with intracranial neoplasms in between the duration of 1 year was conducted. Pre-operative contrast-enhanced magnetic resonance imaging and DTI scans of the patients were taken into consideration. Pre- and post-operative neurological examinations were performed and the outcome was assessed.

Inclusion Criteria

- All cases of brain tumor who underwent MRI imaging.

Exclusion Criteria

- Post operative cases of brain tumor.
- Post radiotherapy cases of brain tumor.
- Patient having history of claustrophobia.
- Patient having history of metallic implants in-sertion, cardiac pacemakers and metallic for-eign body in situ.
- Patient clinically unstable

Methods

Conventional Magnetic Resonance Imaging

Magnetic resonance imaging was performed on a 1.5 – Tesla Siemens Magnetom Symphony scanner, Erlangen, Germany using a quadrature head coil. Conventional imaging includes the following: T1WI TR 450- 550msec, TE 8 msec in the sagittal, axial planes, T2 WI TR 4800msec TE 127 msec in axial plane, FLAIR TR 9000- 10,000 msec TE 127 msec in axial plane.

Diffusion Tensor Imaging

Multidirectional diffusion weighted imaging (MDDW), echo-planar images were acquired with a double spinecho sequence (230mm x 230mm x 200 mm FOV, TR 2800 msec, TE 98 msec, 4 acquisitions per series). Diffusion encoding were applied along 6 noncollinear directions (b = 1000), and 1 image was acquired without diffusion encoding. FA, ADC, and eigen vector maps were calculated. We transferred the diffusion-tensor imaging data to an offline workstation which is based on the Fiber Assignment by Continuous Tracking (FACT) method. To aid in the visualization of the fiber tracts, an Red Green Blue (RGB) -orientation color map to demonstrate fiber shape and direction was used. FA and ADC were evaluated in the regions of interest (ROIs) and were compared to contralateral white matter. Cases with bilateral tract involvement were compared with age matched normal controls.

Statistical Analysis

Data was entered into Microsoft excel data sheet and was analyzed using SPSS 22 version software. Categorical data was represented in the form of Frequencies and proportions. Continuous data was represented as mean and standard deviation. ANOVA test was used as test of significance to identify the mean difference between more than two groups. Paired t test was used to compare FA and ADC between normal contralateral white matter with other lesions. p value <0.05 was considered as statistically significant.

Results

Table 1: Age and gender distribution of subjects, Distribution of patients according to number of lesions, Type of lesions Mass effect caused by the lesion, White matter involvement

		Frequency	Percent
Age	<30 yrs	6	12
	31 to 40 yrs	14	28
	41 to 50 yrs	8	16
	51 to 60 yrs	12	24
	>60 yrs	10	20
Gender	Female	12	24
	Male	38	76
No of lesions	Intra axial	30	70
	Extra axial	20	40
Type of lesions	Solid	36	72
	Necrotic	8	16
	Cystic	2	4
	Solid and necrotic	2	4
	Solid and cystic	2	4
Mass Effect	Nil	15	30
	Present	35	70
White matter Involvement	Destroyed	6	12
	Displacement	24	48
	Edematous	10	20
	Infiltration	10	20

The mean age of the patients was 47.3 years (range 23-71 years). In the study most of the patients were in the age group 31 to 40yrs and 51 to 60 years. Among the 50 cases, 38 were men and 12 were women. Among 50 patients, 30 were intra axial lesion and 20 were extra axial lesion. Most of the cases were solid in nature, rest were necrotic, solid and cystic, solid and necrotic and cystic. Majority of the cases were showing mass effect in the form of compression on the ventricular system, effacement of cortical sulci or basal cisterns, midline shift or herniation.

Table 2: Comparison of FA and ADC in Displaced white matter lesions

		Mean	Std. Deviation	p value
FA	Contralateral Normal White Matter	0.492	0.125	<0.0001
	Tumor	0.158	0.092	
	Contralateral Normal White Matter	0.507	0.128	<0.0001
	Tumor Border	0.258	0.142	
	Contralateral Normal White Matter	0.502	-	-
	Edema	0.175	-	
	Contralateral Normal White Matter	0.498	0.122	0.058
	Peritumoral white matter	0.452	0.104	
ADC	Contralateral Normal White Matter	0.725	0.032	0.064
	Tumor	1.146	0.074	
	Contralateral Normal White Matter	0.718	0.034	0.007
	Tumor Border	1.016	0.084	
	Contralateral Normal White Matter	0.76	0.04	-
	Edema	1.72	0.04	
	Contralateral Normal White Matter	0.72	0.034	0.452
	Peritumoral white matter	0.78	0.055	

Table 3: Comparison of FA and ADC in Destroyed white matter lesions

		Mean	Std. Deviation	p value
FA	Contralateral Normal White Matter	0.478	0.062	0.004
	Tumor	0.1028	0.017	
	Contralateral Normal White Matter	0.476	0.064	0.132
	Tumor Border	0.258	0.12	
	Contralateral Normal White Matter	0.47	0.033	0.118
	Edema	0.15	0.0185	
	Contralateral Normal White Matter	0.477	0.066	0.088
	Peritumoral white matter	0.2525	0.182	
ADC	Contralateral Normal White Matter	0.72	0.052	0.232
	Tumor	1.18	0.08	
	Contralateral Normal White Matter	0.74	0.054	0.276
	Tumor Border	1.126	0.14	
	Contralateral Normal White Matter	0.686	0.024	0.108
	Edema	1.62	0.04	
	Contralateral Normal White Matter	0.73	0.0520	0.184
	Peritumoral white matter	0.825	0.045	

Table 4: Comparison of FA and ADC in Infiltrated white matter lesions

		Mean	SD	p value
FA	Contralateral Normal White Matter	0.52	0.128	0.007
	Tumor	0.16	0.098	
	Contralateral Normal White Matter	0.51	0.122	0.008
	Tumor Border	0.23	0.056	
	Contralateral Normal White Matter	0.56	0.106	0.008
	Edema	0.14	0.035	
	Contralateral Normal White Matter	0.50	0.118	0.212
	Peritumoral white matter	0.44	0.086	
ADC	Contralateral Normal White Matter	0.78	0.074	0.012
	Tumor	1.15	0.306	
	Contralateral Normal White Matter	0.76	0.075	0.007
	Tumor Border	1.086	0.201	
	Contralateral Normal White Matter	0.72	0.081	0.03
	Edema	1.68	0.156	
	Contralateral Normal White Matter	0.76	0.075	0.756
	Peritumoral white matter	0.77	0.052	

Table 5: Comparison of FA and ADC in Edematous white matter lesions

		Mean	Std. Deviation	p value
FA	Contralateral Normal White Matter	0.486	0.214	0.007
	Tumor	0.061	0.015	
	Contralateral Normal White Matter	0.496	0.164	0.012
	Tumor Border	0.066	0.046	
	Contralateral Normal White Matter	0.600	0.202	0.048
	Edema	0.168	0.042	
	Contralateral Normal White Matter	0.488	0.214	0.138
	Peritumoral white matter	0.400	0.142	
ADC	Contralateral Normal White Matter	0.776	0.054	0.096
	Tumor	1.400	0.732	
	Contralateral Normal White Matter	0.772	0.032	0.028
	Tumor Border	1.115	0.176	
	Contralateral Normal White Matter	0.800	0.062	0.005
	Edema	1.643	0.075	
	Contralateral Normal White Matter	0.776	0.054	0.248
	Peritumoral white matter	1.064	0.535	

White matter pathway involvement was identified in all patients by using anisotropy, color coded DT imaging maps and 3DMR Tractography. Normal white matter pathways demonstrated on DT imaging appeared unaffected in contralateral hemisphere. The WM tracts were color coded in a universal fashion based on their spatial orientation.

Discussion

Over the following 30 years, there was an explosion of technological and scientific advancement in the field of MRI. Scanners became faster and more sensitive, and MR phenomena that initially created problems and artifacts, soon became the basis for new imaging techniques. [13] Improvements in MR imaging hardware and computer capabilities led to faster image acquisition techniques and allowed imaging of rapidly changing physiological processes. [14] Magnetic resonance (MR) imaging and MR spectroscopy plays an important role in the detection and evaluation of brain tumors. In the past few years, however, a number of advanced MR imaging techniques have been developed that provide new methods for the assessment of brain tumors. One of these techniques is diffusion tensor imaging (DTI). [15]

Extensive tumor resection can reduce the risk of relapse (particularly gliomas with low grade malignancy) and allow subsequent radiotherapy or chemotherapy to be more effective. On the other hand, sparing ''functionally relevant'' zones and therefore preservation of motor, visual or language functions significantly improves the quality of life of these patients. DTI is a noninvasive imaging technique that provides information about tissue microstructure and architecture by measuring the average and directional variation of water diffusivity for a given voxel in terms of ADC and FA, respectively. DTI provides information on the directionality of water molecules at the cellular level, thus indicating the orientation of fiber tracts. Diffusion tensor calculations permit the characterization of diffusion in heterogeneously oriented tissue. The spatial orientation of myelinated fiber tracts can then be represented as distinct white matter maps in easily read, color- coded directional maps. [16] The mean age of the patients was 47.3 years (range 23-71 years). In the study most of the patients were in the age group 31 to 40yrs and 51 to 60 years. Among the 50 cases, 38 were men and 12 were women. Among 50 patients, 30 were intra axial lesion and 20 were extra axial lesion. Most of the cases were solid in nature, rest were necrotic, solid and cystic, solid and necrotic and cystic.

Majority of the cases were showing mass effect in the form of compression on the ventricular system, effacement of cortical sulci or basal cisterns, midline shift or herniation. White matter pathway involvement was identified in all patients by using anisotropy, color coded DT imaging maps and 3DMR Tractography. Normal white matter pathways demonstrated on DT imaging appeared unaffected in contralateral hemisphere. The WM tracts were color coded in a universal fashion based on their spatial orientation. The most significant use of DTI, in particular, is to preoperatively confirm the integrity and location of displaced white matter tracts. White matter tracts may be pathologically altered by the tumor in several ways; specifically, they may be displaced, infiltrated by tumor and/or edema, or destroyed. Four imaging patterns were identified that presumably reflected these alterations on FA-weighted directional color maps. Unfortunately, however, these alterations are not mutually exclusive in a given tumor or even in a given white matter tract. [17]

Smits et al [18] had incorporated fMRI and DTI in the preoperative assessment in a series of patients with brain tumors. They showed that tracking of the CST directly from the fMRI activation area can be used to visualize and distinguish the different components of the CST, especially the hand and foot fibers. In a healthy volunteer, the presented method showed that the tracked hand, foot, and lip fibers follow a distinct course, the foot fibers coursing posteromedially to the hand fibers within the posterior limb of the internal capsule (PLIC). Smits et al [18] showed that tracking the CST based only on anatomic landmarks may not be sufficient to visualize reliably the CST and that fMRI-based seed region-of-interest placement may be necessary to visualize the CST in its entirety. Furthermore, DT tractography of the CST was seen to be hampered in cases of anatomic distortion due to a mass effect of the lesion or in cases of altered diffusivity due to tumor infiltration or perifocal edema in the region of the CST. Tracking improved when the fMRI-based seed region-of-interest approach was used, thus providing more reliable preoperative information. New techniques such as evaluation of fiber density mapping (FDM) which represents quantification of the extent of destruction of white matter (WM) structures in the center, transition zone, and border zone of intracranial gliomas were not assessed in this study. FDM provides histologic insight into the structure of WM; therefore, it may help prevent post treatment neurologic deficits when planning therapy of brain tumors. [19]

Conclusion

DTI provides crucial information regarding the infiltration of the tract and their displaced course due to the tumor. This study indicates that it is a very important tool for the preoperative planning of surgery. The involvement of WM tracts is a strong predictor of the surgical outcome. The effect of brain tumor on white matter pathways is much better evaluated with the aid of DTI than on conventional MRI. The white matter tracts were characterized based on anisotropy, fiber orientation or direction into four patterns – displaced, infiltration, edematous and destroyed. There can be one or more of four distinct patterns of white matter tracts alteration by the tumor.

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