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DTI correlates of cognition in term children with spastic diplegic cerebral palsy

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ABSTRACT

Background and aims: Presently, there is no published study that shows association between cognition and white matter injury in spastic cerebral palsy. We aimed to correlate cognitive functions with diffusion tensor imaging derived metrics in spastic diplegic children.

Methods: Twenty-two term children with spastic diplegia and 22 healthy controls were recruited. All patients were graded on the basis of gross motor function. The Indian children intelligence Test was used to quantify cognition and diffusion tensor imaging was used to quantify microstructural changes in various white matter regions. Diffusion tensor imaging metrics were quantified by placing regions of interests in different white matter regions like corona radiata, anterior limb of internal capsule, posterior limb of internal capsule, mid brain, pons, medulla, genu, splenium, temporal white matter, parietal white matter, frontal white matter and occipital white matter.

Results: Spastic diplegic children showed significantly lower neuropsychological test scores as compared to controls. A significantly decreased fractional anisotropy values were observed in corona radiata, anterior limb of internal capsule, posterior limb of internal capsule, mid brain, pons, medulla, genu, splenium and occipital white matter; however significantly increased mean diffusivity values were observed in corona radiata, anterior limb of internal capsule, posterior limb of internal capsule, mid brain, pons and genu in spastic diplegic as compared to controls. A significant positive correlation in fractional anisotropy and negative correlation in mean diffusivity was observed with neuropsychological test scores.

Conclusion: These results suggest that these imaging metrics may be used as a biomarker of cognitive functions in term children with spastic diplegia.

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1. Introduction

The cerebral palsy (CP), primarily a motor disorder, is often accompanied by disturbances of sensation (vision or hearing), cognition, communication, perception (understood as the capacity to incorporate and interpret sensory information), behavior and seizure disorder.[1] It is classified into four major types: spastic, ataxic, athethoid/dyskinetic and mixed. Spastic CP is characterized by dysfunction in corticospinal tracks leading to increase muscles tone, hyperreflexia and the persistence of primitive reflexes.[2] Further spastic CP is subcategorized as spastic hemiplegia, diplegia and quadriplegia. Spastic diplegia is characterized by asymmetrical bilateral spasticity and is often associated with periventricular leukomalacia (PVL).[3–7] The worldwide incidence of CP is 2–2.5 per 1000 live births.[8] The prevalence of this disorder among preterm and very preterm infants is substantially higher.[9,10] In the developing world, the prevalence of cerebral palsy is not well established but estimates are 1.5–5.6 cases per 1000 live births.

Neuropsychological studies have shown association of cerebral palsy with higher prevalence of psychiatric disorder[11] and learning disability.[12] Some have reported no differences between patients and controls[13–15] while others have shown significant changes in performance and executive functions in diplegic CP compared to controls.[16–18] These spastic diplegic children have shown significant improvement in verbal IQ but no change in performance two years following school admission.[19]

Studies using conventional magnetic resonance imaging (MRI) have reported brain abnormalities in 70–90% children affected with CP.[20] Children with spastic diplegia or quadriplegia frequently have White matter (WM) injury.[21–23] Occurrence of PVL is more frequently reported in children with spastic diplegia than in children with teraplegia or hemiplegia and central atrophy is more frequent in tetraplegic group in comparison to diplegic group.[24] Several studies have associated visuoperceptual impairment with WM reduction in the parietal and occipital lobes in groups of children with spastic CP.[25–27] Fedrizzi et al.[28] have reported the association of visuoperceptual impairment with lesions involving the optic radiation, degree of ventricular dilatation and thinning of posterior body of corpus callosum. They found significant correlation of these lesions with performance IQ but not verbal IQ in preterm children with spastic diplegia.[28]

Conventional MRI helps to identify WM abnormalities; however it does not provide information regarding the extent of its injury.[29,30] With availability of diffusion tensor imaging (DTI) on clinical scanner, it provides quantitative information about restrictions in the random movement of water molecules by macromolecules and myelin and utilized to visualize brain WM tracts. Brain water preferentially diffuses parallel to fiber bundles, rather than perpendicular to them. Thus, the measurement of diffusion orientation conveys interesting information about brain anatomy that has not been accessible through conventional imaging techniques. Fractional anisotropy (FA) and mean diffusivity (MD) are two of the most commonly used metrics for characterizing tissue microstructural organization. MD is the spatially averaged magnitude of water diffusion. FA provides additional information regarding the directionality of diffusion, and reflects a complex combination of multiple factors, including axonal membrane integrity, myelination level, axonal density, and coherence.[31,32]

Several studies have reported the WM injury in CP children on DTI.[33–35] However, these studies have focused only on its association with motor function[36–40]; and none have studied its association with cognition.

We hypothesize that neuro-cognition would correlate significantly with DTI derived metrics in spastic CP children. In the present study an attempt has been made to quantify cognitive function and DTI metrics in term spastic diplegic children and age/sex matched healthy controls with an aim to correlate DTI derived metrics with cognitive outcomes.

2. Materials and methods

2.1. Subjects

Clinically diagnosed 22 children with spastic diplegic CP (mean age 7.72 ± 2.6, 8 female and 14 male) and 22 healthy controls (8.59 ± 1.7, 4 female and 18 male) without any neurological or cognitive deficit and with normal MRI examination were recruited. The institutional ethics committee approved the study, and informed consent was obtained from parents of the children with CP as well as controls. All these children were born at term (37–40 weeks gestational age) and had no history of seizures. **All children were right handed. Left handed subjects were excluded from the study.** The diagnosis of CP was based on clinical observations: delayed motor milestones, abnormal neurologic examination, persistence of primitive reflexes, and abnormal postural reactions. All patients were assessed with standard clinical examination, gross motor function measure (GMFM) scale[41] and modified Ashworth scale (to measure spasticity) jointly by experienced neurologist as well as physiotherapist. Patients were graded according to GMFM scale that is based on a functional, five-level classification system for CP on self-initiated movement with particular emphasis on sitting and walking.[42] In the current study all 22 children with spastic diplegia were grade II. On the basis of intelligence quotient (IQ) all the 22 children with CP had mild mental retardation (IQ = 50–69).

2.2. Inclusion criterion

Spastic diplegia CP children with age ranging from 4 to 12 years were included in the study. Children with natal or post natal evidence of hypoxic ischemic insult either on MRI, or based on history obtained by parents or the combination of above two were included. Children with motor disability and DQ/IQ > 50/34, GMFM score ranging from 50 to 60 were included in the study.

2.3. Neuropsychological evaluation

The neuropsychological test battery was performed by expert clinical psychologist for assessing cognition of CP children as well as controls by using Indian adaptation of the Revised

Amsterdamse Kinder Intelligence (RAKIT) Test.[43] The Indian Children Intelligence Test (ICIT) consist of 9 subtests which include Closure (50 items) measures perception, Exclusion (50 items) measures cognition of similarity and differences, Memory span (36 items) measures immediate memory span of concrete and abstract objects, verbal meaning (60 items) measures knowledge of concept and verbal conceptualization, Mazes (14 items) measures visual motor coordination, Learning name (12 items) measures learning and remembering, Quantity (65 items) measures quantitative conceptual ability, Discs (18 items) measures spatial orientation and speed of spatial visualization and Hidden figures (45 items) measures attention and working memory. NPT was administered before sedation and MRI. Few minutes break was given after subtest 3 and subtest 7. For each subtest, beginning and ending items are fixed for the three age groups, group I contain 4 years 2 months–6 years 2 months, group II consists of 6 years 2 months–8 years 2 months and group III consists of 8 years 2 months–11 years 2 months.

2.4. Sedation

All children were sedated prior to MRI examination by an experienced anesthesiologist. Patients were deprived of solid food for 6 h and liquids for 3 h prior to MRI examination. Children were sedated with sevoflurane 5–6% in air oxygen mixture (50:50) using inhalational induction technique with bag and mask. After children lost consciousness, a laryngeal mask airway of appropriate size was inserted in to the oropharynx and anesthesia was maintained with sevoflurane 2–3% in air oxygen mixture. All children were monitored with pulse oximetry and non invasive blood pressure monitoring. At the end of imaging sequence, the sevoflurane vapourizer was switched off and laryngeal mask airway was removed after oropharyngeal suctioning. After completion of MRI examination (typically lasting between 30 and 40 min), patients were moved to the recovery ward, where they were observed until they were fully conscious. All control children under went MRI examination without any sedation.

2.5. MRI protocol

Whole brain conventional MRI and DTI were performed on a 3-Tesla GE MRI system (Signa Hdxt, General Electric, Milwaukee, USA). All imaging was performed in the axial plane and had identical geometrical parameters. The conventional MR imaging protocol included T2-weighted fast spin echo with echo time (TE)/repetition time (TR)/number of excitations (NEX) = 70 ms/6820 ms/1/no. of slice = 46/slice thickness = 3 mm/field of view (FOV) = 240 mm^2, T2-fluid-attenuated inversion recovery (FLAIR) TE/TR/NEX = 80 ms/9000 ms/1/no. of slice = 46/slice thickness = 3 mm/FOV = 240 mm^2, Fast Spoiled Gradient Echo Brain Volume (3D FSPGR BRAVO) with TE/TR/NEX/inversion time/flip angle = 3.32 ms/8.4 ms/1/400 ms/13/slice thickness = 1 mm/FOV = 240 mm with image matrix = 288 × 288.

DTI data were acquired using a single-shot echo-planar dual spin echo sequence with ramp sampling on. The diffusion tensor encoding used was a vender-supplied DTI scheme with 30 uniformly distributed directions. DTI was performed in the axial plane and had identical geometrical parameters: the diffusion weighting b factor was set to 1,000 s/mm^2, FOV = 240 × 240 mm^2, slice thickness = 3 mm, NEX = 1, interslice gap = 0 and number of slices = 46 with acquisition matrix of 128 × 128. DTI data were processed as described in detail elsewhere.[44]

2.6. Data analysis

The DTI metrics, such as FA and MD were calculated by using in-house developed JAVA-based software.[44] The DTI derived maps were displayed and overlaid on T2-weighted images to facilitate region-of-interest (ROIs) placement. ROIs of a size ranging from 5 × 5 to 2 × 2 pixels were placed on different white matter regions (Fig. 1); corona radiata (CR), anterior limb of internal capsule (ALIC), posterior limb of internal capsule (PLIC), mid brain (MB), pons, medulla, genu, splenium, temporal white matter (TWM), frontal white matter (FWM), parietal white matter (PWM) and occipital white matter (OWM).[37,45] FA and MD values were quantified from the right and left hemispheres in patients and controls (Fig. 2). ROIs in patients as well as controls were placed at same anatomic landmark (as described above), and at the same time on two parallel workstations repeatedly (two times), by two observers (RKG, SKC) independently to ensure consistency across the two studies. The average of left and right hemisphere regions for each parameter was used for analysis. At the time of ROIs placement, observers were blinded to the patient's clinical as well as neuropsychological status. Neuropsychological assessment of CP children was performed by expert clinical psychologist. She was blinded to the MR imaging findings.

2.7. Sample size estimation and statistical analysis

We assumed that average of FA, MD and neuropsychological score for CP children were 0.4 ± 0.1, 0.9 ± 0.05, 10 ± 5 and for control 0.5 ± 0.1, 0.8 ± 0.05, 20 ± 0.05 respectively. We used independent *t*-test to compare the difference at $p = 0.05$ and 90% power for a two tailed hypothesis. Under above assumptions the minimum number of cases required was 22. Student's independent *t* test was performed to evaluate the differences in DTI metrics (FA and MD) quantified from different white matter regions and neuropsychological (closure, exclusion, memory span, verbal meaning, mazes, learning name, quantity, discs and hidden figures) score between CP children and healthy controls. Bivariate analysis of correlation was performed to study the possible association of DTI metrics with neuropsychological scores of spastic CP children as well as controls. All statistical analyses were performed using SPSS (version 16.0, SPSS Inc, Chicago, IL, USA) statistical software.

3. Results

All children with CP showed significantly lower NPT scores for closure ($p < 0.001$), exclusion ($p < 0.001$), memory span ($p < 0.001$), verbal meaning ($p < 0.001$), mazes ($p < 0.001$), learning name ($p < 0.001$), quantity ($p < 0.001$), discs

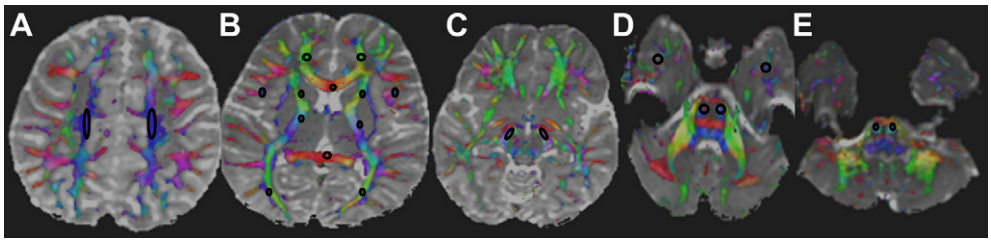

Fig. 1 – Shows placement of ROIs on corona radiata (A), frontal white matter, genu, parietal white matter, anterior limb of internal capsule, posterior limb of internal capsule, splenium and occipital white matter (B), mid brain (C), temporal white matter and pons (D) and medulla (E).

($p < 0.001$) and hidden figures ($p < 0.001$) as well as IQ score ($p < 0.001$) as compared to healthy controls (Table 1).

A significantly decreased FA values were observed in CR, ALIC, PLIC, MB, pons, medulla, genu, splenium and OWM; however significantly increased MD values were observed in CR, ALIC, PLIC, MB, pons and genu in CP children as compared to healthy controls (Table 2).

A significant positive correlation was observed between FA values in ALIC and 9 subtest of NPT scores. FA value of PLIC, pons and OWM regions showed significant positive correlation with 8 subtests of NPT scores. The FA values of CR, MB, medulla, PWM, splenium, genu also showed a significant positive correlation with different subtests of NPT scores. A significant positive correlation was also observed between IQ score and FA values of CR, ALIC, PLIC, MB, pons, medulla, genu, splenium, PWM and OWM (Table 3).

MD values in CR and genu showed a significant negative correlation with 8 and 6 subtests of NPT scores respectively. MD values in PLIC, pons and OWM also negatively correlated with various NPT scores. In addition, IQ showed significant negative correlation with CR, PLIC, pons, genu, splenium and OWM (Table 3).

When diplegic CP patients were sub-grouped into (i) Low performance and normal Verbal IQ ($n = 8$) and (ii) Low performance and low Verbal IQ ($n = 14$), we observed significantly decreased FA value in TWM and OWM regions in later group as compared to the former (Table 4).

4. Discussion

In the present study, children with spastic diplegia showed significantly lower NPT scores as compared to healthy controls. Significant decrease in FA values and increase in MD values were observed in various white matter regions of term spastic diplegia as compared to controls. Significant positive correlation was observed between FA values and NPT scores, while significant negative correlation was observed between MD values and NPT scores.

Impaired visuoperceptual ability among preterm spastic diplegic children has been reported in previous studies.[25–28,39,40] Koeda et al.[27] found impairments of visuoconstruction tests in preterm children with spastic diplegia. Schatz et al.[46] found that children with spastic diplegia demonstrate deficits in learning paired associates, involving visual nonverbal responses. Fedrizzi et al.[28] showed that preterm spastic diplopic children showed significant discrepancy in verbal and performance IQ. Pagliano et al.[47] compared term

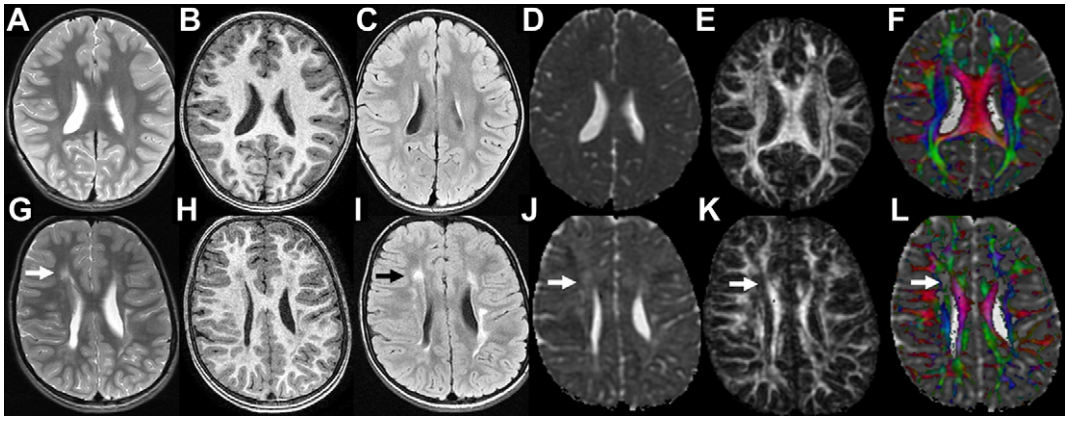

Fig. 2 – Shows comparison of conventional MRI and diffusion tensor imaging (DTI) in a age and sex matched control (A–F) and 9-year-old boy with spastic diplegia (G–L). The periventricular leukomalacia is clearly evident on T2-weighted fast spin echo (G) and fluid attenuated inversion recovery (I) images in the patient. On DTI-derived mean diffusivity (MD) (J), fractional anisotropy (FA) (K) and color coded FA overlaid on MD map (L) demonstrate the abnormalities in patient (arrows) as compared to the corresponding images/maps in control subject. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1 – Summary of mean neuropsychological test scores in spastic diplegic children and healthy controls.

Neuropsychological measures	Spastic diplegic children ($n = 22$) (Mean ± SD)	Healthy controls ($n = 22$) (Mean ± SD)	*p-Value
Closure	5.64 ± 3.12	17.41 ± 7.6	<0.001
Exclusion	4.55 ± 4.0	16.91 ± 8.76	<0.001
Memory span	4.05 ± 4.72	16.36 ± 6.8	<0.001
Verbal meaning	10.14 ± 6.39	22.32 ± 7.14	<0.001
Mazes	3.82 ± 5.38	16.86 ± 9.67	<0.001
Learning name	10.68 ± 6.39	19.00 ± 5.03	<0.001
Quantity	5.50 ± 6.23	20.09 ± 8.37	<0.001
Discs	3.64 ± 5.91	20.64 ± 6.15	<0.001
Hidden figures	9.14 ± 7.5	20.64 ± 8.67	<0.001
IQ	62.05 ± 16.34	116.86 ± 22.84	<0.001

*Only significant values are shown in the table.
Note: IQ, intelligence quotient.

and preterm children with spastic diplegia and found greater visuoperceptual compromise in preterm compared to term diplegics. However both groups had similar cognitive performance and conventional MRI findings. They concluded that the strabismus present in preterm children may have contributed to their greater visuoperceptual compromise as compared to term diplegics. In the current study, term children with spastic diplegia showed impaired visuoperception (visual organization, visual discrimination, and visual recognition), visuoconstruction abilities and are in line with previous studies conducted on preterm spastic diplegia.[25–40]

We also observed poor performance on verbal test which measures immediate memory span, learning, quantitative ability and verbal conceptualization. Performance on verbal tests typically depends on the level of motor, intellectual and sensory impairment, which might have lead to the observed findings in the current study. We observed Lower IQ score in term children with spastic dilegia compared to controls. Previous studies reported lower Wechsler performance IQ and no difference in Wechsler verbal IQ between preterm spastic diplegia and healthy control.[19,28] Our results of impaired cognition in term spastic diplegic children are consistent with previous studies performed on preterm children[25–40] and suggest that term and preterm spastic diplegic children may have similar cognitive deficit.

Table 2 – Summary of mean DTI metrics (FA and MD) in spastic diplegic children and healthy controls.

	Spastic diplegic children ($n = 22$) (Mean ± SD)	Healthy controls ($n = 22$) (Mean ± SD)	*p-Value
	FA		
CR	0.45 ± 0.07	0.52 ± 0.07	<0.001
ALIC	0.47 ± 0.05	0.64 ± 0.09	<0.001
PLIC	0.58 ± 0.04	0.62 ± 0.04	<0.001
MB	0.58 ± 0.05	0.62 ± 0.04	<0.001
Pons	0.42 ± 0.07	0.52 ± 0.05	<0.001
Medulla	0.28 ± 0.06	0.36 ± 0.07	<0.001
Genu	0.67 ± 0.07	0.72 ± 0.04	0.02
Splenium	0.69 ± 0.11	0.77 ± 0.05	0.02
OWM	0.42 ± 0.07	0.54 ± 0.07	<0.001
	MD($\times 10^{-3}$ mm^2/s)		
CR	0.89 ± 0.06	0.83 ± 0.03	<0.001
ALIC	0.86 ± 0.05	0.83 ± 0.04	<0.001
PLIC	0.88 ± 0.05	0.84 ± 0.02	<0.001
MB	0.92 ± 0.05	0.86 ± 0.04	<0.001
Pons	0.76 ± 0.06	0.72 ± 0.04	<0.001

*Only significant values are shown in the table.
Note: DTI, diffusion tensor imagines; FA, fractional anisotropy; MD, mean diffusivity; CR, corona radiate; ALIC, anterior limb of internal capsule; PLIC, posterior limb of internal capsule; MB, mid brain and OWM, occipital white matter.

It is well known that FA values reflect the integrity of white-matter tracts while MD reflects changes in cell component and extracellular space.[48–50] The reduction in FA values in white matter regions can be attributed to fiber disruption, misalignment, edema or axonal degeneration.[50] Drobyshevsky et al.[51] have also shown in their rabbit model that low FA values in the internal capsule, CR, and corpus callosum in hypertonic kits compared with control subjects and related these observations with white matter fiber tracts injury. In patients with cerebral palsy, a significant decrease in FA values has been observed in the various tracts which show improvement following treatment.[37] The structural disorganization of the white matter fiber tracts has been reasoned for the decrease in FA values, while the restoration of the integrity of white matter tracts has been attributed to the improvement of FA values. In the current study, we observed significantly reduced FA values (CR, ALIC, PLIC, MB, pons, medulla, genu, splenium, PWM, and OWM) and significantly increased MD values (CR, ALIC, PLIC, MB, pons, and genu) in children with CP as compared to the controls, indicating microstructural white matter abnormalities. The reduction in FA along with the increased MD values in CP children suggests disorganization of the structural barriers to molecular diffusion of water.

FA values measured from ALIC, PLIC, MB, pons, medulla, PWM and OWM regions positively correlated With NPT scores while MD values in CR, genu, PLIC, FWM, pons and OWM negatively correlated with various NPT scores in the current study. Recent studies have shown association between visuoperceptual impairment and reduction in white matter of the parietal and occipital lobes on conventional MRI in group of children with spastic diplegia.[29,30,42] Schmithorst et al.[52] found positive correlations of IQ scores with FA

Table 3 – Pearson correlation of FA and MD values with NPT.

Regions (FA)	Closure	Exclusion	Memory	VM	Mazes	LN	Quantity	Discs	HF	IQ
CR	.30*	.30*	.39*	.33*	.34*	.39**		.32*		.38*
ALIC	.54**	.57**	.69**	.48**	.55**	.45**	.50**	.56**	.41**	.65**
PLIC	.44**	.48**	.50**	.39**	.35*	.44**	.46**	.44**		.53**
MB	.38**	.49**	.36*	.38*			.42**	.35*	.39**	.45**
Pons	.41**	.42**	.58**	.32*	.43**	.51**	.42**	.53**		.54**
Medulla		.41**	.31*	.46**	.31*	.41**	.44**	.48**	.41**	.46**
Genu			.32*	.42**		.31*	.38**		.39**	.34*
Splenium			.34*	.34*	.49**		.39**	.35*		.37**
PWM		.33*		.37*		.36*	.36*	.43**	.45**	.34*
OWM		.43**	.59**	.53**	.43**	.47**	.45**	.61**	.44**	.55**
MD										
CR	−.44**	−.48**	−.29**	−.36**		−.39**	−.45**	−.47**	−.36**	−.46**
ALIC								−.37**		
PLIC	−.32*	−.31*					−.30*	−.38**		−.34**
Pons				−.30*		−.32**	−.29*		−.36**	−.35**
Genu				−.43**	−.30*	−.45**	−.34**	−.37**	−.37**	−.41**
Splenium				−.33*						−.31**
OWM				−.33**				−.43**		−.32**

** = significant at .01 level, * = significant at .05 level.
Note: FA, fractional anisotropy; MD, mean diffusivity; NPT, neuropsychological test; VM, verbal meaning, LN, learning name; HF, hidden figure; IQ, intelligence quotient; CR, corona radiate; ALIC, anterior limb of internal capsule; PLIC, posterior limb of internal capsule; MB, mid brain; PWM, posterior white matter and OWM, occipital white matter.

values in white matter association areas (including frontal and occipitoparietal regions) in 47 normal children. Kontis et al.[53] have reported association between IQ performance and microstructure changes observed on DT tractography in the genu of the corpus callosum of adults who were born preterm.

The internal capsule contains thalamocortical, and other cortical projection fibers where the anterior limb (ALIC) have connections between the thalamus and prefrontal cortex.[54] Posterior limb (PLIC) contains connections between thalamus and motor, somatosensory, and other parietal cortex.[54] Pons, MB and medulla are involved in motor control and sensory analysis. Our results reveal that the integrity of white-matter tracts in motor sensory pathway can influence motor function as well as cognition; however, more brain areas might also be involved in cognition. It is well known that OWM is directly related to various visual functions.[29,30,42] In this study, significant association between OWM and most of the subtests of NPT related to visuoperceptual and visuoconstructive abilities is consistent with the aforementioned fact. The significant association between FA in various motor and sensory pathways and verbal test suggests that several of the tracts involved are probably a part of the anatomy underlying language function. Successful performance on the performance subtests of ICIT requires an element of timed performance with bimanual coordination and spatial reasoning (Maze and Discs). This requires the coordinated action of several brain areas and is likely to be dependent on intact and functioning white matter. Since IQ is a composite of multiple cognitive process associated with the structure and function of several connected brain regions,[55] the observed association between IQ and DTI metrics in white matter tracts, is justified.

In the present study, diplegic children with normal verbal IQ showed significantly high FA in TWM and OWM as compared to those having abnormal verbal IQ suggest that children with abnormal verbal IQ have increased micro-structural changes in these regions and may influence these abnormalities. Peng et al.[56] have observed positive correlation of verbal IQ with FA value from the parieto-occipital central white matter in patients with malignant phenylketonuria (PKU). It is known that temporal lobe is involved in auditory processing as well as semantics in speech, language and vision which supports our findings.

We conclude that significant correlation of FA and MD values with NPT scores suggests that the microstructural alteration in the white matter regions may be responsible for the impairment in cognitive functions. These DTI metrics may be used as an image biomarker of cognition in term children with spastic diplegia. However, these metrics may be influenced by the scanner field strength and chosen imaging parameters and should be considered while making interpretation.

Table 4 – Summary of mean DTI metrics (FA) in spastic diplegic children having low performance and normal verbal IQ ($n = 8$) vs low performance and low verbal IQ ($n = 14$).

Regions (FA)	Low performance and normal verbal IQ (Mean ± SD)	Low performance and low verbal IQ (Mean ± SD)	*p
TWM	0.36 ± 0.03	0.27 ± 0.07	0.02
OWM	0.48 ± 0.06	0.40 ± 0.07	0.03

*Only significant values are shown in the table.
Note: DTI, diffusion tensor imagines; FA, fractional anisotropy; TWM, Temporal white matter; OWM, occipital white matter.

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