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Diffusion Tensor Imaging Derived Metrics in the Assessment of White Matter Tracts in Children with Developmental Delay

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Abstract

Background: Neuroimaging is crucial in diagnosing developmental delay, yet some children exhibiting significant cognitive or motor deficits may show no abnormalities on standard MRI scans. Diffusion tensor imaging (DTI), however, offers a more detailed evaluation of white matter organization, providing both qualitative and quantitative insights into the integrity of association, commissural, and projection fibers within the brain.

Aim of Study: The aim of this study is to evaluate white matter tract microstructural injury in children with developmental delay using diffusion tensor metrics and three-dimensional tractography.

Patients and Methods: This cross-sectional study included 20 patients with developmental delay and 10 controls. Magnetic resonance imaging included T2, T1 3-dimensional magnetization-prepared rapid acquisition gradient-echo, fluid attenuation inversion recovery, and diffusion tensor imaging. Tractography was performed using Brainance MD software, version v3.5.0 . DTI color maps were analyzed for any color asymmetry. Fractional anisotropy, Mean diffusivity values were calculated from 38 regions of interest. Data were analyzed using SPSS software (Mac release 21 versions).

Results: Asymmetrical tracts with decreased thickness were seen in 17 patients, partial non-crossing of corticospinal tracts in 4 and decreased color vectarity in 17 patients. Fractional anisotropy values were mostly lower in patients than controls (33 regions: 86.8%); this was statistically significant at the bilateral forceps minor and major, bilateral anterior corona radiata, left posterior corona radiata, left cingulate gyrus and corpus callosum genu. Mean diffusivity values were higher in patients in 26 regions (68.4%) and lower in 12 regions (31.6%).

Conclusion: Diffusion tensor imaging metrics and color maps can safely detect compromised white matter tracts in children with developmental delay and assist in early rehabilitation. Important tracts to be evaluated include bilateral forceps minor and major, bilateral anterior corona radiata, left posterior corona radiata, left cingulate gyrus and genu of the corpus callosum.

Key Words: *DTI – Derived metrics – White matter tracts in children – Developmental.*

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Introduction

A CHILD is said to present with developmental delay (DD), if he/she have failed to acquire the expected developmental skills, in comparison to children of the same age. A significant delay is defined by a performance two or more standard deviations (SD) below the mean **[1]** in two or more developmental areas which include motor function (gross/fine), language & speech, cognition, personal and social/play skills **[2,3].**

Childhood DD and subsequent disabilities are major health issueswith a significant proportion of children presenting with physical/mental disabilities. There is an ongoingraising awareness with development of data collection systems to better characterize and estimate the prevalence of DD **[4].**

Neuroimaging plays an important role in the diagnosis of DD, however children with clear cognitive or motor abnormalities might present with unremarkable conventional scans **[5,6].**

Diffusion tensor imaging (DTI) allows for detailed assessment of white matter structure in the brain, with an informative qualitative and quantitative visualization of the integrity of the white matter association, commissural and projection fibers **[7].**

Quantitative parameters that can be used to detect postulated, underlying white matter damage in

DD include fractional anisotropy (FA) and mean diffusivity (MD) **[8]**. Low FA values occur with myelin loss while elevated MD values are usually seen with poor axonal integrity. 3D visualization of white matter tracts on DTI derived tractography enables to visualized injured tracts and the extent of fiber loss **[9,10,11].**

The aim of this study is to evaluate the prevalence of white matter tracts microstructural injury in a pediatric population presenting with DD, by the use of diffusion tensor metrics and 3D tractography. We are therefore, aiming to validate the use of easy, noninvasive diffusion tensor imaging in the assessment of childhood DD, in our practice.

Material and Methods

Study population:

This cross-sectional study received the approval of the ethical committee at our hospital. Cases were selected from the patients referred to us in the pediatric radiology department of Abu El Reesh Pediatric Hospital for MRI brain, as a part of their clinical protocol during the course of evidence-based management between August 2024 and January 2025. DTI was performed by us as an addition.

Twenty patients (age range: 2-13 years) were included (14 males, 6 females). We selected patients above 2 years old as normal myelination completes by 18-24 months of age. An established clinical diagnosis of global developmental delay (GDD) was confirmed by the referring pediatric neurologist and was based on the presence of: A significant delay in 2 or more developmental domains (gross motor/ fine motor/cognition/speech & language/personal & social) and a performance at least 2SD below the mean for age appropriate.

Ten controls (age range: 3-14 years, 6 males, 4 females) were selected for comparison, from children being referred to our department for brain MRI for indications other than GDD. They didn't present with any neurological deficit or any of the established criteria of GDD.

We excluded patients less than 2 years old, any patient with a past history of previous head trauma or ischemic brain injury as well as any patients with previous/ongoing cranio-spinal infection, systemic or chronic disease, or morphological MR abnormality on conventional MRI brain.

MRI imaging:

MR brain imaging was performed for both cases and controls on a Siemens 1.5 Hdxt MRI machine equipped with apediatric head coil.

The following were acquired: A T1-weighted sagittal 3-dimensional magnetization-prepared rapid acquisition gradient-echo (3D MPRAGE) sequence [TR: 7.1ms, TE: 3.45ms, TI: 1000ms, flip angle 7°, field of view (FOV) 256mm × 256mm, and slab thickness 150mm] for fusion of DTI data, along with T2, and fluid attenuation inversion recovery (FLAIR) sequences. The acquisition matrix was 256 × 192 × 128, giving a reconstructed voxel resolution of 1.0mm × 1.0mm × 1.33mm.

Diffusion tensor imaging:

A single-shot, balanced echo planar imaging sequence (TR: 6000ms, TE: 97ms). Twenty contiguous transverse slices (slicethickness: 5mm) were acquired,oriented parallel to the anterior and posterior commissure planes, covering the brain entirety except for its upper most part. Parameters included: FOV 128 × 128mm, acquisition matrix 128 × 128, with a reconstructed in-plane resolution 1.78mm × 1.78mm, b values 0 and 1000s/mm^2. Total acquisition time was 2 minutes. Eddy current correction was performed using the Eddy correct tool to correct for distortions and patient motion.

Post-processing and analysis:

Data post-processing was performed using Brainance MD software, version v3.5.0.

All images were carefully reviewed to ensure imaging quality and data collection validity.

Qualitative analysis of DTI color and tractography fusion maps was done first to detect any asymmetry of color saturation/hue.

Then, quantitative analysis was done by drawing a region of interest (ROI, diameter 3mm) on the interactive maps, including the following white matter tracts which we selected as they represent the most functionally active brain areas.

1- Right anterior limb internal capsule.
2- Left anterior limb internal capsule.
3- Right posterior limb internal capsule.
4- Left posterior limb internal capsule.
5- Right Forceps minor.
6- Left Forceps minor.
7- Right forceps major.
8- Left forceps major.
9- Right precentral gyrus.
10- Left precentral gyrus.
11- Right postcentral gyrus.
12- Left postcentral gyrus.
13- Body fornix.
14- Right corticospinal tract.
15- Left corticospinal tract.

16- Right medial lemniscus.
17- Left medial lemniscus.
18- Right cerebral peduncle.
19- Left cerebral peduncle.
20- Corpus callosum splenium.
21- Corpus callosum body.
22- Corpus callosum genu.
23- Right anterior corona radiata.
24- Left anterior corona radiata.
25- Right superior corona radiata.
26- Left superior corona radiata.
27- Right posterior corona radiata.
28- Left posterior corona radiata.
29- Right sagittal stratum (including inferior longitudinal fasciculus and inferior fronto-occipital fasciculus).
30- Left sagittal stratum.
31- Right cingulate gyrus.
32- Left cingulate gyrus.
33- Right hippocampus.
34- Left hippocampus.
35- Right superior longitudinal fasciculus.
36- Left superior longitudinal fasciculus.
37- Right tapetum.
38- Left tapetum.

Mean FA, and MD values of the 38ROIs were extracted from the skeletonised DTI volumes of each subject (cases and controls).

Statistical analysis:

The SPSS software (Statistical Package for the Social Science; SPSS Inc., Chicago, IL, USA), release 21 versions for Mac was used. Mean ± standard deviation (SD) or number/percentage (%) were used for data expression.

Intergroup comparison of both variables FA and MD, for each of the white matter tracts selectedwas done by using the paired Student *t*-test.

Chi square test was used to find the significance in categorical data with *p*-values : <0.05 = Significant, <0.01 = Highly significant and >0.05 = Non-significant.

Results

Characteristics of the study participants:

There was no statistically significant difference between cases (n=20) and controls (n=10) as regards to the gender distribution (Chi-square=0.032, *p*-value=0.8580. Not significant).

The median age for patients was 4.275±3.9 and was 4.73±3.6 for the controls, with no statistically significant age distribution difference (independent *t*-test value=0.23662, *p*-value=0.4 not significant).

Imaging results:

All patients selected had normal conventional MRI morphological images.

Quantitative evaluation:

Our analysis of 38 ROIs in the patient group yielded an MD and an FA value for each region and we calculated the mean and SD for each parameter in the cases and control groups.

The MD values were higher in patients than controls in 26 regions (68.4%) (Table 1).

The MD values were lower in 12 regions (31.6%). The latter included the right forceps major, bilateral pre and post central gyrus, right anterior corona radiata, bilateral posterior corona radiata, left sagittal stratum, left superior longitudinal fasciculus, right tapetum and splenium of the corpus callosum.

However, this intergroup comparison was not statistically significant for the exception of the right tapetum where MD was lower in patients than controls with *p*-value=0.0057.

The FA values were mostly lower in patients than controls, this was seen in 33 regions (86.8%) (Table 2).

Regions with statistically significant reduced FA in patients as compared to controls included bilateral forceps minor and major, bilateral anterior corona radiata, left posterior corona radiata, left cingulate gyrus and genu of the corpus callosum.

Higher FA values in patients compared to controls were seen in 5 regions (13.2%). The latter were left pre central gyrus, bilateral post central gyrus, body of the fornix (with statistically significant difference between the 2 groups) and right tapetum (not statistically significant).

Qualitative evaluation:

Patients had abnormal findings such as asymmetrical tracts with decreased thickness and girth in 17 out of twenty patients (Figs. 1,2,3).

Partial non crossing of cortico-spinal tracts was observed in 4 patients (Fig. 4). Decreased color vectarity was seen in 17 patients on colored RGB maps when compared to control cases.

Table (1): White matter tracts with higher MD values in patients compared to controls.

Region of measurement	Cases (mean MD+/-SD)	Controls (mean MD+/-SD)	Student *t*-test *p*-value significant versus not significant
1- Right anterior limbinternal capsule	0.000907+/-0.000219901	0.000821526+/-3.35E-05	NS
2- Left anterior limbinternal capsule	0.000899+/-0.000460807	0.00083592 9+/-0.000835929	NS
3- Right posterior limbinternal capsule	0.000918+/-0.000286581	0.00080529+/-3.52E-05	NS
4- Left posterior limbinternal capsule	0.00084+/-0.000161864	0.000812756+/-0.000161864	NS
5- Right Forceps minor	0.000956+/-0.000122038	0.000921529+/-3.78E-05	NS
6- Left Forceps minor	0.000924+/-0.000104051	0.000906499+/-5.73E-05	NS
7- Left Forceps Major	0.000943+/-0.000160073	0.000883975+/-9.40E-05	NS
8- Body Fornix	0.001686+/-0.000571007	0.001379611+/-0.00024197	NS
9- Right corticospinal tract	0.000899+/-7.35527E-05	0.000862906+/-0.000163991	NS
10- Left corticospinal tract	0.000897+/-8.95731E-05	0.00088343+/-0.000156243	NS
11- Right medial lemniscus	0.001162+/- 0.000595069	0.000934452+/-0.000232567	NS
12- Left medial lemniscus	0.001124+/- 0.000617112	0.000904405+/-0.000163611	NS
13- Right cerebral peduncle	0.001081+/-0.000164482	0.000954165+/-0.000167765	NS
14- left cerebral peduncle	0.001108+/-0.00035919	0.001056857+/-0.000276569	NS
15- Left anterior corona radiata	0.000998+/-0.000160264	0.000947113+/-4.83E-05	NS
16- Right superior corona radiata	0.000968+/-0.000263304	0.000880206+/-7.29E-05	NS
17- Left superior corona radiata	0.000963+/-0.000247389	0.000900591+/-6.09E-05	NS
18- Right sagittal stratum	0.001017+/- 0.000100006	0.000986934+/-0.000142611	NS
19- Right cingulate gyrus	0.000955+/-0.000174881	0.000890834+/-3.15E-05	NS
20- Left cingulate gyrus	0.001022+/-0.000320409	0.000886319+/-5.51E-05	NS
21- Right hippocampus	0.001045+/-0.000207913	0.001038834+/-0.000183772	NS
22- Left hippocampus	0.001066+/-0.000269328	0.000994899+/-0.000108678	NS
23- Right superior longitudinal fasciculus	0.000956+0.000216446	0.0009197+/-6.72E-05	NS
24- Left tapetum	0.027765+/-0.082654903	0.001635553+/-0.000330654	NS
25- Genu corpus callosum	0.001112+/-0.00013315	0.00100702+/-0.000175908	NS
26- Body corpus callosum	0.020894+/-0.06222898	0.001381258+/-0.000432915	NS

MD: Mean diffusivity. SD: Standard deviation. NS: Not statistically significant.

Table (2): White matter tracts with lower FA values in patients compared to controls.

Region of measurement	Cases		Controls		Student *t*-test *p*-value significant versus not significant
	Mean FA	SD	Mean FA	SD	
1- Right anterior limb internal capsule	0.3052	0.096641146	0.352808587	0.084081125	NS
2- Left anterior limb internal capsule	0.2743	0.075421851	0.311099051	0.106006248	NS
3- Right posterior limb internal capsule	0.3981	0.164259585	0.486123124	0.129493473	NS
4- Left posterior limb internal capsule	0.4258	0.137210139	0.516257799	0.119231337	NS
5- Right Forceps minor	0.4265	0.106046374	0.555737734	0.054259914	*p*-value=0.0012 SS
6- Left Forceps minor	0.4197	0.111866041	0.52314481	0.057357494	*p*-value=0.0107 SS
7- Right Forceps Major	0.4998	0.096999198	0.628455169	0.109835857	*p*-value=0.0028 SS
8- Left Forceps Major	0.4761	0.160164811	0.655522162	0.095428395	*p*-value=0.0030 SS
9- Right precentral gyrus	0.3613	0.10914725	0.423602612	0.053495505	NS
10- Right corticospinal tract	0.2682	0.105500711	0.307898067	0.076555277	NS
11- Left corticospinal tract	0.2832	0.111473764	0.292876662	0.090923746	NS
12- Right medial lemniscus	0.323	0.126964562	0.358584346	0.092408565	NS
13- Left medial lemniscus	0.3254	0.125426561	0.378902549	0.091402646	NS
14- Right cerebral peduncle	0.3236	0.124394712	0.387460427	0.092506928	NS
15- Left cerebral peduncle	0.3479	0.134504399	0.3911198	0.134636646	NS
16- Right anterior corona radiata	0.2551	0.065398692	0.325387044	0.100266416	*p*-value=0.0280 SS
17- Left anterior corona radiata	0.2502	0.063071036	0.318137275	0.101003047	*p*-value=0.0312 SS
18- Right superior corona radiata	0.3128	0.093103049	0.340563402	0.119514048	NS
19- Left superior corona radiata	0.3	0.085713995	0.300734616	0.113597567	NS
20- Right posterior corona radiata	0.2934	0.085606594	0.348687109	0.09312098	NS
21- Left posterior corona radiata	0.2911	0.067971317	0.377186986	0.094686827	*p*-value=0.0078 SS
22- Right sagittal stratum	0.2741	0.09130833	0.297924075	0.095248597	NS
23- Left sagittal stratum	0.294333333	0.089174236	0.308665645	0.071898535	NS
24- Right central gyrus	0.19826	0.045247571	0.242745968	0.08224555	NS
25- Left central gyrus	0.1891	0.047664219	0.302729891	0.096575386	*p*-value=0.0002 SS
26- Right hippocampus	0.2117	0.082193606	0.198478704	0.078147181	NS
27- Left hippocampus	0.1964	0.043321024	0.214170993	0.087595141	NS
28- Right superior longitudinal fasciculus	0.2785	0.074304553	0.334684708	0.085864416	NS
29- Left superior longitudinal fasciculus	0.2596	0.067148591	0.301285925	0.079834893	NS
30- Left Tapetum	0.235279	0.099730819	0.289395007	0.071122101	NS
31- Genu corpus callosum	0.3053	0.117792709	0.417862561	0.157184026	*p*-value=0.0358 SS
32- Body corpus callosum	0.220041	0.108960019	0.302530104	0.130433006	NS
33- Splenium corpus callosum	0.383	0.146607564	0.498371381	0.195425047	NS

FA: Fractional anisotropy. SD: Standard deviation. NS: Not statistically significant. SS: Statistically significant.

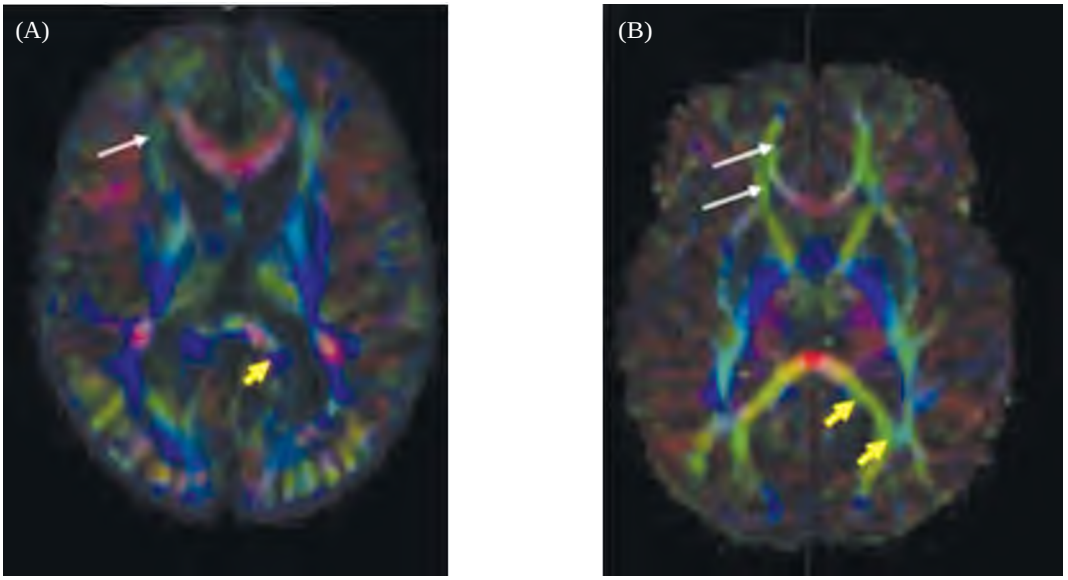

Fig. (1): White Matter Abnormalities in a Three-Year-Old with Developmental Delay. Axial directional maps: (A) Three-year-old patient with developmental delay; (B) Three- year- old control. White arrows show reduced fibers of anterior regions of corona radiata and forceps minor in comparison to the control one. Yellow arrows show reduced cingulum fibers and forceps major in the patient.

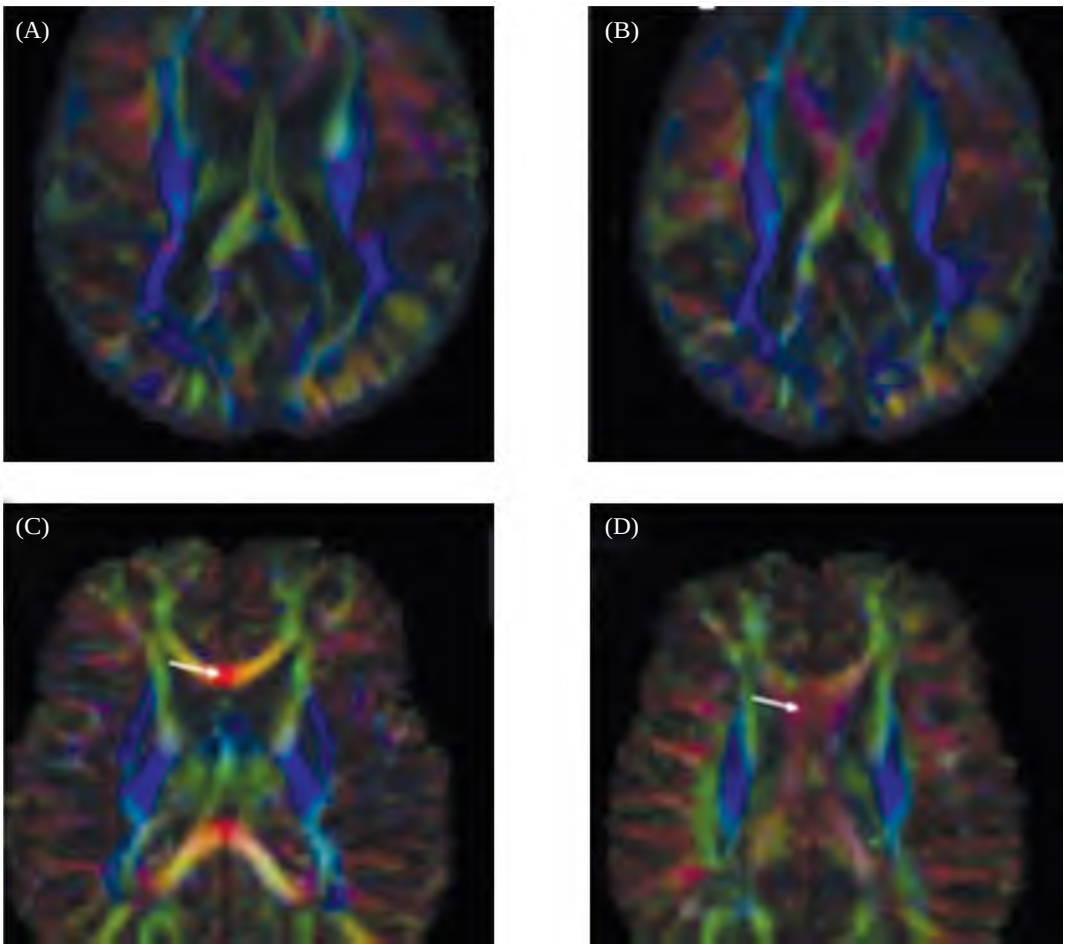

Fig. (2): Fiber Integrity Differences in a Four-Year-Old with Developmental Delay Axial directional maps: (A,B): Four-year-old patient with developmental delay, (C,D): Four-yearold control. Reduced red commissural fibers (arrow), and green association fibers in affected ones.

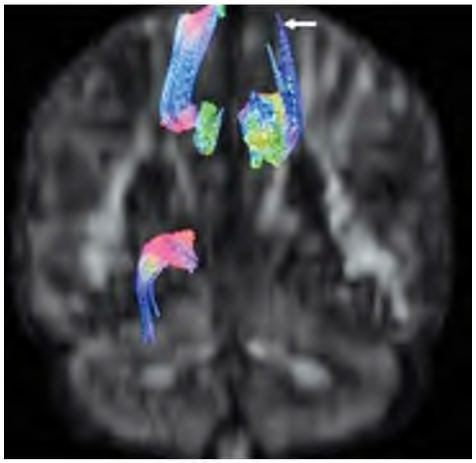

Fig. (3): Tractography Revealing Cingulum Defect in a Six-Year-Old Patient Axial 3D color-coded diffusion tensor fiber tractography in a six-year-old patient with developmental delay: Defect in left cingulum, with mainly reduced fibers in left parahippocampal and superior longitudinal fasciculus (white arrow).

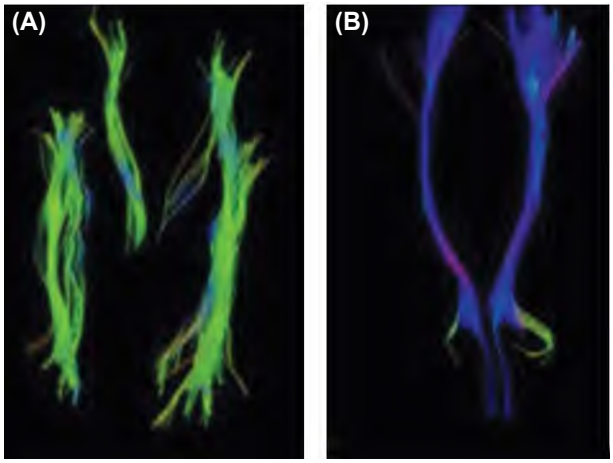

Fig. (4): Tractography Analysis in a Ten-Year-Old with Developmental Delay Ten-year-old patient with developmental delay: Tractography images show (a) defects in left anterior thalamic radiation, and right inferior fronto-occipital fasciculus. FA values were lower than controls. Also, FA values were lower in the right inferior fronto-occipital fasciculus (0.236) than the left (0.265) (b) partial non crossing of corticospinal tracts.

Discussion

Early diagnosis and subsequent rehabilitation can help children with developmental delay. However, often seen negative results on a conventional MRI study represent a challenge for neuro-pediatricians and their patients' family members. We aimed to emphasize the role of DTI-derived metrics in this particular scenario in a pediatric population presenting clinically with developmental delay.

White matter tract integrity in healthy children has been studied qualitatively and quantitatively by MRI DTI derived metrics and colored RGB (red-green-blue) maps, with quantitative parameters including fractional anisotropy and apparent diffusion constant/MD showing progressive changes associated with white matter maturation in normally growing children **[12].** With normal development, there is increased integrity and alignment of tracts and therefore anisotropy **[13].**

Twenty patients above 2 years old presenting with confirmed developmental delay were studied as well as 10 control cases for comparison over a cross section of referrals to our hospital radiology department. There was a close match in the age range between controls and cases. By analyzing diffusion tensor metrics fractional anisotropy (FA) and mean diffusivity (MD) we observed significant microstructural changes affecting multiple white matter regions. Notably, FA values were lower in 33 regions (86.8%) in patients compared to controls, with statistically significant reductions in bilateral forceps minor and major, bilateral anterior corona radiata, left posterior corona radiata, left cingulate gyrus, and the genu of the corpus callosum. MD values were higher in 26 regions (68.4%) and lower in 12 regions, though statistical significance was only noted in the right tapetum. These findings reinforce the importance of DTI-derived metrics as non-invasive biomarkers for evaluating white matter integrity in children with DD.

Our results align with previous research: When compared to healthy controls, our patient cohort showed qualitative white matter tract abnormalities denoting microstructural defects such as asymmetry, decreased girth of fibers, partialnon-crossing at the cortico-spinal tracts and decreased color vectarity on RGB maps. This was also observed by Verma A et al., **[13]** in a study done on fifty cases of DD and 15 age sex matched controls (2-12 years old), where significant decreased fiber thickness and tract density was reported at the corpus callosum on qualitative inspection compared to the controls.

Many studies have used diffusion tensor imaging (DTI) metrics to assess how microstructural abnormalities in the brain impact cognitive and motor development, and our findings largely align with these established observations.

Corpus callosum alterations:

The corpus callosum plays a key role in communication between brain hemispheres, making it crucial for motor coordination and cognitive processing. We found significantly reduced fractional anisotropy (FA) in the genu of the corpus callosum, which is consistent with previous studies by Verma et al., **[13]** Filippi et al., **[14]** and Cascio et al. **[15].** These researchers also noted FA reductions in the corpus callosum among children with DD, reinforc-

ing the idea that disruptions in this structure can contribute to developmental challenges. Estep et al., *[16]* further linked lower FA values to motor impairments in children born prematurely, while Yeatman et al., *[17]* identified early white matter abnormalities affecting callosal diffusion metrics.

Forceps minor and major:

Our findings also showed reduced FA in the forceps minor and major, which is consistent with prior studies suggesting these tracts play a role in cognitive and motor functions. Verma et al., *[13]* observed significant FA reductions in the same regions in children with DD, highlighting their importance in neural connectivity. Since these tracts extend from the corpus callosum, their impairment further emphasizes the broader communication challenges seen in affected children.

Corona radiata and internal capsule:

Filippi et al., *[14]* previously identified lower FA in the corona radiata in children with DD, and our study supports these observations, particularly in the bilateral anterior corona radiata and left posterior corona radiata. This region helps link cortical areas with subcortical structures, meaning its damage can affect movement and higher cognitive functions. The posterior limb of the internal capsule has also been studied in relation to motor impairment, with Estep et al., *[16]* finding FA alterations in this region among children with developmental delays. Our study noted lower FA in this area, though it was not statistically significant likely due to sample size limitations.

Cingulum and hippocampal connectivity:

The cingulum, which is closely connected to the limbic system, is crucial for language and emotional processing. We found significant FA reductions in the left cingulate gyrus, which aligns with findings by Lee et al. *[18]*, who reported that lower FA in this region was linked to weaker language and social-emotional performance. Similarly, Cui et al., *[19]* noted a correlation between cingulum integrity and cognitive and language outcomes in children with DD. The hippocampus, another structure involved in memory and learning, also showed FA changes in our study, further reinforcing the idea that children with DD may experience broader connectivity issues affecting multiple brain functions.

MD Variations and white matter integrity:

Mean diffusivity (MD) provides insight into axonal integrity, with higher values often indicating disrupted fiber structure. We observed increased MD in 26 regions, a pattern comparable to findings from Ackermann et al. *[8]* and Verma et al. *[13]*, who also reported elevated MD as a marker of white matter microstructural damage. However, some regions in our study exhibited lower MD, particularly the right tapetum, which was statistically significant (p=0.0057). While most studies associate higher MD with impaired white matter integrity, this finding suggests a more complex relationship between diffusivity and developmental delay.

Although our findings align with much of the existing literature, there are some differences in regional focus. For example, Ramli et al. *[20]* found lower FA values in the superior cerebellar peduncle and uncinate fasciculus in children with DD, but our study did not specifically assess these tracts. Variations in sample size, imaging protocols, and analysis techniques could explain these discrepancies.

Limitations:

While this study provides valuable insights into white matter integrity in children with developmental delay (DD), it has some limitations. Since the study is cross-sectional, it does not allow for tracking how white matter structures evolve over time, which would be beneficial in understanding developmental changes. A larger sample size would strengthen the statistical power and improve how well the results apply to a broader population. Additionally, using automated region-of-interest (ROI) selection may introduce variability in measurements, potentially affecting the precision of our findings. Another challenge is the absence of pediatric-specific DTI software, which might lead to minor misregistration errors during data processing.

Implications for patient care:

Detecting white matter abnormalities early in children with DD is crucial for shaping effective intervention strategies. Conventional MRI often fails to reveal subtle microstructural changes, making DTI a valuable complementary tool in assessing these deficits. By identifying affected white matter tracts early, clinicians can tailor rehabilitation programs to address specific motor, cognitive, and language challenges. This targeted approach may significantly improve developmental outcomes and enhance quality of life for affected children.

Future directions:

Looking ahead, future studies should focus on longitudinal research to track how white matter tracts develop over time in children with DD. Expanding the sample size and utilizing more refined, pediatric-specific DTI software could enhance accuracy and reliability. Additionally, investigating the relationship between DTI metrics and clinical assessments of motor and cognitive function would offer deeper insights into how microstructural changes influence developmental outcomes. These efforts could help refine diagnostic approaches and improve individualized treatment plans, ultimately leading to better care for children with developmental challenges.

In conclusion, the DTI metrics known as FA and MD along with the qualitative evaluation of

RGB maps can safely and non-invasively suggest a compromised white matter tract microstructure and hence maturation status in children with DD compared to normal children. Important tracts to be evaluated include bilateral forceps minor and major, bilateral anterior corona radiata, left posterior corona radiata, left cingulate gyrus and genu of the corpus callosum. This might help to improve early rehabilitation in children with developmental delay.

Acknowledgment:

Not applicable.

Declaration of conflicting interests:

The authors declare that they have no conflicts of interest.

References

1- CHOO Y.Y., AGARWAL P., HOW C.H., et al.: Developmental delay: Identification and management at primary care level. Singapore Med. J., 60: 119-123, 2019.

2- BATTAGLIA A. and CAREY J.C.: Diagnostic evaluation of developmental delay/mental retardation: An overview. Am. J. Med. Genet C Semin Med. Genet, 117: 3-14, 2003.

3- ABDELGHAFFAR T.S., ABU MADYAN N.A., METWALY N.A., et al.: Role of brain magnetic resonance imaging in assessment of pediatric developmental delay. Med. J. Cairo Univ., 88: 115-124, 2020.

4- EL-MOSELHY E., EL-AZAB R., KHALIFA H., et al.: Epidemiological study of childhood disabilities: A household survey in four Egyptian governorates. Egypt J. Hosp. Med., 20: 66-82, 2005.

5- ARIDAS J.D., YAWNO T., SUTHERLAND A.E., et al.: Detecting brain injury in neonatal hypoxic-ischemic encephalopathy: Closing the gap between experimental and clinical research. Exp. Neurol., 261: 281-290, 2014.

6- KRISHNAN P. and SHROFF M.: Neuroimaging in neonatal hypoxic-ischemic encephalopathy. Indian J. Pediatr., 83: 995-1002, 2016.

7- HU H.H. and MCALLISTER A.S.: The potential and promise of diffusion tensor MRI in predicting neurodevelopment in children. Radiology, 292: 188-189, 2019.

8- ACKERMANN C., ANDRONIKOU S., SALEH M.G., et al.: Diffusion tensor imaging points to ongoing functional impairment in HIV-infected children at age 5, undetectable using standard neurodevelopmental assessments. AIDS Res. Ther., 17: 20, 2020.

9- BROWN-LUM M., IZADI-NAJAFABADI S., OBERLANDER T.F., et al.: Differences in white matter microstructure among children with developmental coordination disorder. JAMA Netw Open, 3: 201184, 2020.

10- FAWZY D.H., SEIF EL-DIEN H.M. and HASSEN R.Z.: The role of diffusion tensor imaging (DTI) in developmental brain anomalies in pediatric age group. Med. J. Cairo Univ., 86: 731-731, 2018.

11- LATHITHA S.V.P., VINAYAKA U.S. and SAHANA K.S.: Role of diffusion tensor imaging in children with developmental delay. Eur. J. Mol. Clin. Med., 9: 5195-5210, 2022.

12- INDER T.E. and HUPPI P.S.: In vivo studies of brain development by magnetic resonance techniques. Ment Retard Dev. Disabil Res. Rev., 6: 59-67, 2000.

13- VERMA A., SAGAR N.C., KUMAR A., et al.: Diagnostic value of diffusion tensor imaging-derived metrics as biomarkers of cerebral changes in developmental delay. Indian J. Radiol. Imaging, 25: 415-420, 2015.

14- FILIPPI C.G., LIN D.D.M. and TSIOURIS A.J.: Diffusion-tensor MRI in children with developmental delay: Preliminary findings. Radiology, 229: 44-50, 2003.

15- CASCIO C., STYNER M. and SMITH R.G.: Reduced relationship to cortical white matter volume revealed by tractography-based segmentation of the corpus callosum in young children with developmental delay. Am. J. Psychiatry, 163: 2157-2163, 2006.

16- ESTEP M.E., SMYSER C.D., ANDERSON P.J., et al.: Diffusion tractography and neuromotor outcome in very preterm children with white matter abnormalities. Pediatr Res., 76: 86-92, 2014.

17- YEATMAN J.D., BEN-SHACHAR M., BAMMER R., et al.: Using diffusion tensor imaging and fiber tracking to characterize diffuse perinatal white matter injury: A case report. J. Child Neurol., 24: 795-800, 2009.

18- LEE H.J., KWON H., KIM J.I., et al.: The cingulum in very preterm infants relates to language and social-emotional impairment at 2 years of term-equivalent age. Neuroimage Clin., 29: 102528, 2020.

19- CUI J., TYMOFIYEVA O., DESIKAN R., et al.: Microstructure of the default mode network in preterm infants. AJNR Am. J. Neuroradiol., 38: 343-348, 2017.

20- RAMLI N., YAP A., MURIDAN R., et al.: Microstructural abnormalities found in uncinate fasciculus and superior cerebellar tracts in children with global developmental delay: A feasibility study. Clin. Radiol., 75: 77.e15-77.e22, 2020.

المقاييس المشتقة من تصوير موتر الانتشار فى تقييم مساحات المادة البيضاء لدى الاطفال المصريين الذين يعانون من تأخر فى النمو

يهدف البحث إلى تقييم إصابات المسارات البيضاء فى الأطفال الذين يعانون من تأخر فى النمو باستخدام تصوير موتر الانتشار (DTI). شملت الدراسة ٢٠ طفلاً يعانون من تأخر النمو و١٠ أطفال سليمين للمقارنة، حيث تم إجراء التصوير بالرنين المغناطيسى باستخدام عدة تسلسلات، بما فى ذلك تصوير الموتر. تم تحليل بيانات الانتشار وتحديد القياسات الكمية لمقاييس مثل تباين التجزئة (FA) ومتوسط الانتشار (MD). أظهرت النتائج انخفاضًا ملحوظًا فى قيم FA فى العديد من المناطق البيضاء، خاصةً فى الجسم الثفنى، القشرة الحزامية، والتاج الأمامى، بينما ارتفعت قيم MD فى مناطق أخرى، مما يشير إلى ضعف سلامة الألياف العصبية فى الأطفال المصابين. كشفت الخرائط اللونية وجود عدم تناسق فى التراكيب البيضاء وانخفاض سماكة بعض المسارات العصبية. يسلط البحث الضوء على أهمية DTI كأداة تشخيصية غير جراحية يمكنها الكشف المبكر عن اضطرابات المادة البيضاء، مما يسهل التدخل العلاجى وإعادة التأهيل فى وقت مبكر لتحسين الوظائف الإدراكية والحركية لدى الأطفال المصابين. يقترح الباحثون تعزيز استخدام تقنيات التصوير المتقدمة لتطوير بروتوكولات مخصصة للأطفال.