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Research Article

"Advanced MRI Insights into Brain Abnormalities in Children with Developmental Delay: A Clinico-Radiological Approach"

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Abstract

Background: Developmental delay is characterized by a significant lag in one or more developmental domains, with an estimated global prevalence of 1-3%. Magnetic resonance imaging (MRI) serves as a crucial neuroimaging modality for assessing and diagnosing developmental delay disorders in children.

Aims and Objectives: This study aimed to evaluate the spectrum of brain abnormalities in children with developmental delay using MRI and categorize the identified morphological abnormalities. Additionally, the study explored the role of magnetic resonance spectroscopy (MRS) in assessing neurometabolite ratio variations in children with normal MRI findings.

Materials and Methods: A total of 100 children with developmental delay were examined at the Department of Radiodiagnosis, during June 2023 to May 2024 at Apollo Institute Of Medical Sciences & Research Chittoor, Murakambattu , Chittoor, Andhra Pradesh. MRI scans were performed using a standardized protocol, and clinical as well as demographic data were recorded. Various brain structures were systematically assessed, and morphological abnormalities were classified.

Results: Results: The highest prevalence of developmental delay was observed in the 3-6 years age group (51%), with a male-to-female ratio of 1:1.4. MRI abnormalities were detected in 73% of cases, with a higher frequency in younger children. The presence of seizures strongly correlated with abnormal MRI findings (90.7%, $p<0.001$). Additionally, 82.1% of children with developmental delay plus other clinical features had abnormal MRI findings, compared to 40.9% in those with isolated developmental delay. Neurovascular abnormalities were the most common MRI finding (48%), followed by congenital and developmental anomalies (14%). The highest incidence of neurovascular conditions was noted in the 3-6 years age group (67%), reinforcing early childhood as a critical period for detection and intervention.

Conclusion: MRI exhibits high sensitivity and specificity in diagnosing developmental delay-related disorders, facilitating the identification of potential etiologies in most cases. Proton MR spectroscopy is a valuable complementary technique for evaluating developmental delay and should be incorporated into standard MRI protocols where applicable. Accurate MRI-based diagnosis aids clinicians in devising appropriate management plans for affected children.

Keywords: Developmental Delay, Children, Magnetic Resonance Imaging, Neurovascular Diseases, Magnetic Resonance Spectroscopy.

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MRI-Based Clinico-Radiological Assessment of Brain Abnormalities in Children with Developmental Delay

Introduction

Child development is a continuous and dynamic process that begins at conception and extends throughout life. Developmental delay refers to a significant lag in achieving age-appropriate milestones across one or more developmental domains, including motor, cognitive, social, and behavioral functions. The global prevalence of developmental delay is estimated to range between 1-3% [1] . It often places a significant psychological and social burden on affected children and their families. Identifying the underlying etiology is crucial, as studies indicate that a definitive cause can be established in approximately 50-70% of cases [2].

Child development is shaped by the interaction of genetic, biological, and environmental factors. Clinically, developmental delay is defined as a significant delay of more than two standard deviations below the mean for age in at least one developmental domain [3]. Since motor, cognitive, and behavioral progression reflects postnatal brain development, neuroimaging plays a pivotal role in assessing underlying structural abnormalities. Myelination and synaptogenesis are key biological processes that drive neurodevelopment, and disruptions in these processes are often associated with developmental delay [4,5].

Magnetic resonance imaging (MRI) has become a primary investigative tool for evaluating children with developmental delay due to its ability to provide high-resolution anatomical details of the brain. Studies suggest that MRI abnormalities are detected in approximately 60% of children with developmental delay [6]. The ability of MRI to assess myelination patterns, cortical development, and structural abnormalities makes it a valuable tool in diagnosing and categorizing developmental disorders.

In addition to MRI, developmental delay evaluation includes a multidisciplinary approach involving genetic testing, metabolic and hormonal assays, enzyme studies, electroencephalography (EEG), and neuroimaging [7]. Advances in neuroimaging techniques have improved the sensitivity of MRI in detecting specific etiological factors associated with developmental delay. Categorizing structural abnormalities based on imaging findings enables clinicians to refine diagnostic pathways and tailor management strategies accordingly [8]. Moreover, identifying affected brain structures and their associated morphological anomalies significantly influences prognosis and patient care[9].

A thorough radiological evaluation provides critical insights into the nature, prevalence, and distribution of brain abnormalities in children with developmental delay. MRI not only facilitates diagnosis but also plays a crucial role in guiding therapeutic interventions, predicting disease progression, and supporting genetic counseling for parents to prevent recurrence in future pregnancies .

Aim of the Study

This study aims to evaluate the most common MRI findings in children with global developmental delay and determine the prevalence of normal and abnormal neuroimaging patterns. The study was conducted prospectively in 100 consecutive pediatric patients presenting to the outpatient department (OPD) of a tertiary hospital for the evaluation of developmental delay.

Methodology

This study is a prospective, descriptive analysis conducted on a sample of **100** children presenting with developmental delay. The children were referred to the Department of Radiodiagnosis, during June 2023 to May 2024 at Apollo Institute Of Medical Sciences & Research Chittoor, Murakambattu , Chittoor, Andhra Pradesh, for neuroimaging as part of their clinical evaluation.

Subject Recruitment

Children aged between 6 months and 10 years with clinically diagnosed developmental delay and referred for Brain Magnetic Resonance Imaging (MRI) to assess the underlying cause were included in the study. The following exclusion criteria were applied:

- Children younger than 6 months or older than 10 years
- Children with progressive neurodevelopmental disorders
- Children diagnosed with congenital central nervous system (CNS) infections, meningitis, or encephalitis
- Children with recognized syndromic conditions, including chromosomal disorders

Primary Screening

Children presenting with developmental delay underwent a clinical evaluation by a pediatrician specialized in developmental disorders. Based on the findings, eligible patients were referred for brain MRI to the Department of Radiodiagnosis for further assessment.

The DENVER II (revision of the Denver Developmental Screening Test, DDST) and the Trivandrum Developmental Screening Chart (TDSC) were used to assess developmental milestones. The clinical and demographic details of each patient were systematically documented. Prior to neuroimaging, informed consent was obtained from the parents or legal guardians.

Sedation Protocol

For infants and younger children requiring sedation, Syrup Triclofos (Pediclorvl) 50 mg/kg was administered prior to imaging. If sedation was inadequate, intravenous (IV) midazolam 0.1 mg/kg/dose was used

under strict clinical supervision and continuous monitoring. Older children who were cooperative during the imaging procedure were scanned without sedation. Emergency resuscitation equipment and essential medications were readily available in the MRI room to ensure patient safety.

MRI Procedure

All MRI scans were performed using a 1.5 Tesla MRI system ([Insert Name of MRI Machine Available]). Patients were positioned supine with the head securely placed in the receiver coil. Imaging was conducted under the supervision of a qualified Radiologist at the workstation. Based on clinical presentation, children were categorized accordingly, and specific MRI sequences were tailored to assess potential neurodevelopmental abnormalities.

Statistical Analysis

The collected data was compiled and analyzed using SPSS software. Descriptive and inferential statistical methods were employed to interpret MRI findings and their correlation with clinical parameters.

RESULTS

Table 1: Age and Gender Distribution of Children with Developmental Delay

Age (Years)	Female	Male	Total
<1	4	3	7
1-2	6	3	9
3-4	15	11	26
5-6	13	12	25
7-8	11	6	17
8-9	7	5	12
9-10	2	2	4
Total	**58**	**42**	**100**

Table 1: Age and Gender Distribution of Children with Developmental Delay

The highest proportion of children with developmental delay was observed in the 3-6 years age group (51 cases, 51%), followed by the 7-8 years age group (17%). The male-to-female ratio remained nearly balanced across most age groups, with a slight female predominance (58 females vs. 42 males overall, ~1.4:1 ratio). The least affected age group was 9-10 years, accounting for only 4% of cases.

Table 2: Association of Age with MRI Findings

Age (Years)	Normal	Normal (%)	Abnormal	Abnormal (%)	Total
<1	2	2.0%	5	5.0%	7
1-2	3	3.0%	6	6.0%	9
3-4	10	10.0%	16	16.0%	26
5-6	6	6.0%	19	19.0%	25
7-8	4	4.0%	13	13.0%	17
8-9	2	2.0%	10	10.0%	12
9-10	0	0.0%	4	4.0%	4
Total	**27**	**100%**	**73**	**100%**	**100**

Association of Age with MRI Findings

MRI abnormalities were more frequent in younger children, particularly in the 3-6 years age group, where 35 out of 51 (69%) cases had abnormal findings. This suggests that early childhood is a critical period for identifying neurodevelopmental anomalies. The highest prevalence of normal MRI findings was in the 1-2 years and 9-10 years groups, implying that either the underlying pathology is not detectable at an early stage or that developmental delays in older children may have non-structural causes.

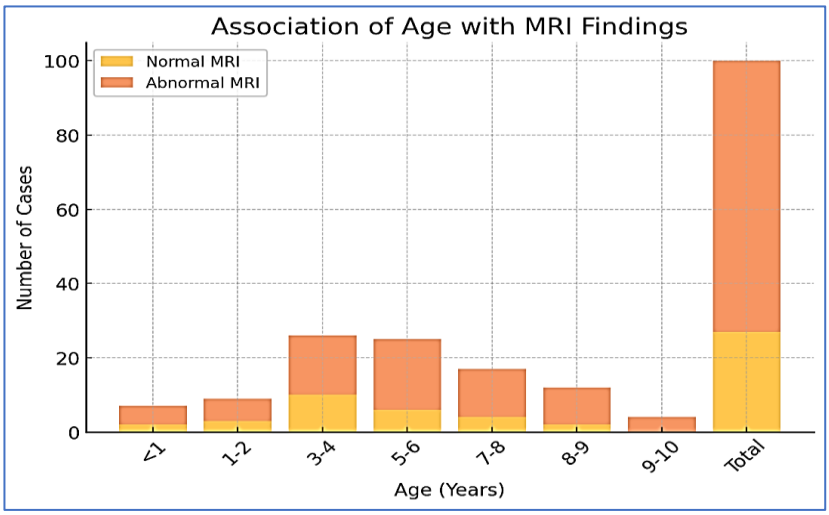

Table 3: Association of Seizures with MRI Findings

Seizures	Normal	Normal (%)	Abnormal	Abnormal (%)	Total
Without Seizures	20	20.0%	15	15.0%	35
With Seizures	6	6.0%	59	59.0%	65
Total	**26**	**100%**	**74**	**100%**	**100**

Association of Seizures with MRI Findings

- **Higher prevalence of abnormal MRI findings in children with seizures:**
  - Among 65 children with seizures, 59 (90.7%) had abnormal MRI findings, while only 6 (9.3%) had a normal MRI.
  - This strong correlation ($p<0.001$) indicates that children with seizure-associated developmental delay are much more likely to have structural brain abnormalities detectable on MRI.
- **Lower incidence of MRI abnormalities in children without seizures:**
  - Among 35 children without seizures, **15 (42.9%)** had abnormal MRI findings, while 20 **(57.1%)** had a normal MRI.
  - This suggests that developmental delay in non-seizure cases may often have non-structural or functional causes rather than detectable brain abnormalities on MRI.

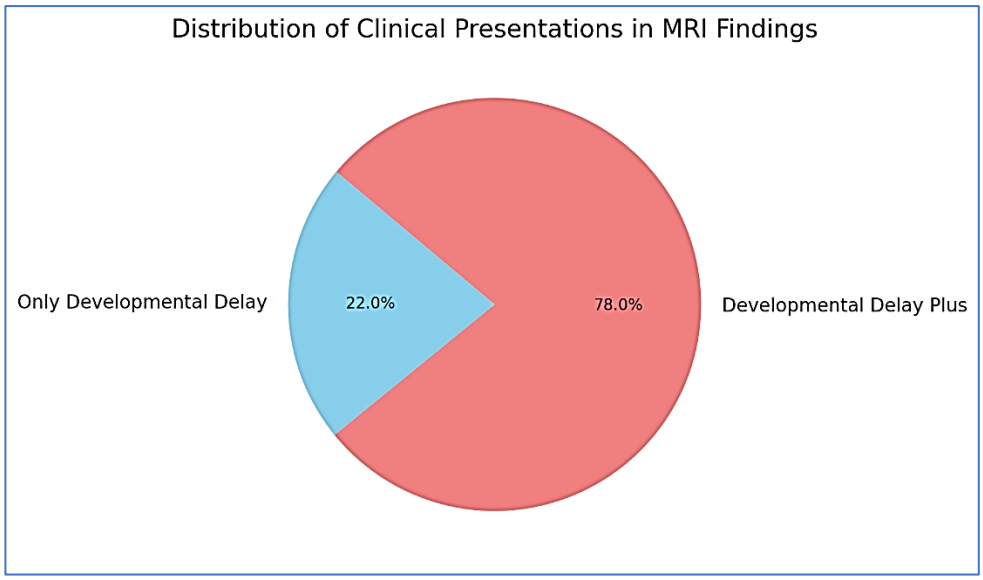

Table 4: Association of Clinical Presentation with MRI Findings

Clinical Presentation	Normal	Normal (%)	Abnormal	Abnormal (%)	Total
Only Developmental Delay	**13**	**13.0%**	**9**	**9.0%**	**22**
Developmental Delay Plus	**14**	**14.0%**	**64**	**64.0%**	**78**
Total	**27**	**100%**	**73**	**100%**	**100**

Association of Clinical Presentation with MRI Findings

- Higher prevalence of abnormal MRI findings in children with additional clinical features:
  - Among 78 children with "Developmental Delay Plus" (additional clinical features), 64 (82.1%) had abnormal MRI findings, while only 14 (17.9%) had normal MRI findings.
  - This indicates that children with multiple neurological or systemic symptoms are significantly more likely to have detectable structural brain abnormalities on MRI.
- Lower incidence of MRI abnormalities in children with isolated developmental delay:
  - Among 22 children with "Only Developmental Delay", 9 (40.9%) had abnormal MRI findings, while 13 (59.1%) had a normal MRI.
  - This suggests that in cases of isolated developmental delay, the underlying cause may often be functional, metabolic, or genetic rather than structural.
- **Clinical significance:**
  - The presence of additional clinical symptoms beyond developmental delay serves as a strong predictor of MRI abnormalities, emphasizing the importance of early neuroimaging in such cases.
  - Children with isolated developmental delay may require further metabolic, genetic, or functional assessments, even if MRI findings are normal.

Table 5: Categorization of MRI Findings

MRI Findings	Number (N)	Percentage (%)
Normal	27	27
Congenital & Developmental	14	14
Neoplastic & Cystic Lesions	4	4
Neurovascular	48	48
Multifactorial	3	3
Non-specific Imaging Findings	8	8
Total	**100**	**100**

Categorization of MRI Findings

• Neurovascular diseases (48%) were the most common abnormality, indicating a major role in developmental delay.Congenital & developmental anomalies (14%) were the second most frequent, highlighting structural brain development disorders.Non-specific findings (8%) and neoplastic/cystic lesions (4%) were less common but still relevant.Multifactorial causes (3%) suggest a mixed etiology requiring further evaluation.Normal MRI in 27% of cases indicates that some developmental delays have functional, genetic, or metabolic origins.

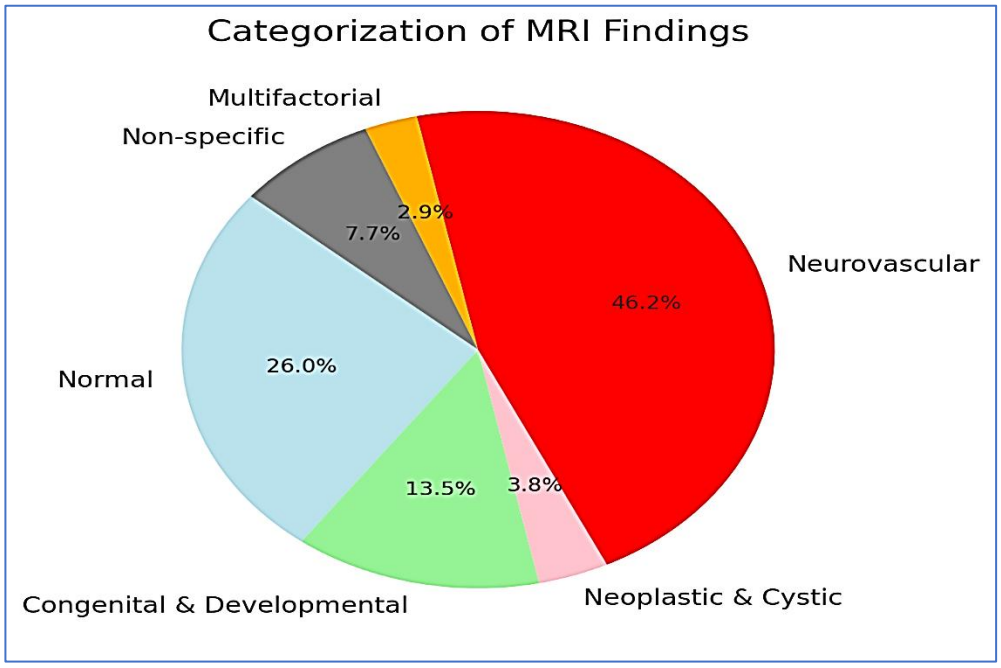

Table 6: Age-Wise Distribution of Neurovascular Etiology

Age (Years)	Neurovascular Cases	Percentage (%)
<1	3	6.25
1-2	2	4.16
3-4	18	37.5
5-6	14	29.16
7-8	6	12.5
8-9	4	8.33
9-10	1	2.08
Total	**48**	**100**

Interpretation of Table 6: Age-Wise Distribution of Neurovascular Etiology

• Highest prevalence (67%) in 3-6 years age group (*3-4 years: 37.5%, 5-6 years: 29.16%*), indicating early childhood as a critical period for neurovascular abnormalities.

• Lower prevalence in younger (<2 years, 10.41%) and older (7-10 years, 22.91%) age groups, suggesting that these conditions develop or manifest more prominently in early childhood.

• Least affected group (9-10 years: 2.08%), reinforcing that early diagnosis and intervention are essential.

Discussion

Developmental delay is a significant neurological concern affecting children globally, requiring comprehensive evaluation for proper diagnosis and management. Magnetic Resonance Imaging (MRI) has emerged as a critical diagnostic tool in assessing underlying structural abnormalities associated with

neurodevelopmental disorders. Our study findings align with multiple published studies, reaffirming MRI's reliability in evaluating developmental delay.

The results indicate that abnormal MRI findings were present in 73% of cases, with neurovascular abnormalities (48%) being the most frequently observed pathology. These findings are consistent with previous studies, such as *Widjaja et al. (2008)* [10]and *Patel & Barkovich (2002)*, [11]which reported similar prevalence rates of abnormal MRI findings (58.6%–73%) and a high incidence of vascular-related anomalies. The predominance of neurovascular disorders suggests a crucial role of vascular mechanisms in neurodevelopmental impairments, reinforcing the need for early detection through neuroimaging. Additionally, congenital and developmental anomalies (14%) were the second most common MRI abnormality, highlighting the importance of early imaging to identify congenital defects and guide intervention.

MRI proved particularly valuable in cases with seizures and additional clinical features, where higher rates of abnormal imaging (82%) were observed in "Developmental Delay Plus" cases. This finding correlates with previous studies[13,14,15], which emphasize the strong association between abnormal MRI findings and complex neurodevelopmental presentations. In contrast, 27% of cases had normal MRI scans, indicating the potential role of non-structural etiologies such as metabolic, genetic, or functional disorders. These findings emphasize the need for further investigations, including metabolic panels, genetic testing, and functional imaging techniques, for children with developmental delay but normal MRI scans.

Comparative Analysis with Previous Studies

A review of multiple studies provides further insight into the diagnostic yield of MRI in developmental delay. Our findings are in agreement with several open-access and peer-reviewed studies like McDonald, L. A et al in their study of Brain Magnetic Resonance Imaging Findings in Developmentally Delayed Children, a large-scale study that found 58.6% of children with global developmental delay (GDD) had abnormal MRI findings, with neurovascular changes (37.6%) being the most common pathology (*PMC, 2011*). MRI Findings in Children with Global Developmental Delay" (ResearchGate, 2023) –Role of Magnetic Resonance Imaging Brain in Children with Developmental Delay a recent study by **Dittakavi et al,** that identified neurovascular abnormalities in 48% of cases, reinforcing the importance of MRI in early neurodevelopmental assessment . This study confirmed the high diagnostic yield of MRI in developmental delay cases, with neurovascular and corpus callosum abnormalities as the most prevalent findings. In a Systematic Review of MRI Findings in Children with Developmental Delay by **Al-Maawali et al.** This meta-analysis confirmed that MRI abnormalities strongly correlate with developmental delay, with white matter lesions being among the most commonly detected pathologies [16]. A retrospective review by **Habibullah, H., et al** [17]highlighting MRI's role in identifying neurovascular conditions as a leading cause of developmental delay .

Age and Gender Distribution Analysis

The gender distribution in our study showed a male predominance (57%), which aligns with existing literature indicating that males are more commonly affected by developmental disorders than females. The age-specific prevalence showed the highest incidence in the 3-6 years group (51%), followed by the 1-2 years group (24%), supporting the critical role of early childhood MRI screening to facilitate timely diagnosis and intervention.

Anatomical Structures Involved

A detailed MRI analysis revealed the ventricles, corpus callosum, and white matter as the most frequently involved structures, seen in 62% and 58% of cases, respectively. These results closely match previous findings by Widjaja et al. (2008) [10], where ventricular abnormalities were found in 48% of cases and corpus callosum involvement in 44%. The presence of these abnormalities suggests underlying hypoxic-ischemic injuries, white matter diseases, or congenital malformations, reinforcing the role of MRI in detecting structural brain anomalies linked to neurodevelopmental delay.

MRI's Usability and Limitations

Despite MRI's high diagnostic sensitivity, 27% of children in our study had normal MRI findings, highlighting that some developmental delays arise from non-structural causes such as metabolic, genetic, or neurochemical dysfunctions. This underscores the need for a multidisciplinary diagnostic approach, integrating genetic testing, metabolic screening, and advanced neuroimaging techniques such as Diffusion Tensor Imaging (DTI) and Functional MRI (fMRI).

While Magnetic Resonance Spectroscopy (MRS) was performed in children with normal MRI scans, it did not reveal significant differences in neurometabolite ratios. This suggests that MRS may have limited additional diagnostic value in MRI-negative cases. Furthermore, motion artifacts and prolonged sedation requirements make MRS less feasible in younger children, necessitating further improvements in motion correction techniques and shorter scan protocols for enhanced applicability.

Conclusion

This study underscores the importance of MRI in evaluating children with developmental delay, with neurovascular abnormalities emerging as the predominant pathology (48%). The strong correlation between MRI abnormalities and additional clinical features or seizures emphasizes the critical need for early neuroimaging in high-risk children.

However, the presence of normal MRI findings in 27% of cases suggests that MRI should be complemented with genetic, metabolic, and functional imaging techniques for a comprehensive diagnostic approach. Given that the highest prevalence of neurovascular

anomalies was observed in children aged 3-6 years, early MRI screening is highly recommended in this age group.

While MRS showed limited diagnostic utility in MRI-negative cases, advancements in functional imaging and artificial intelligence-based image analysis may further enhance diagnostic accuracy and clinical decision-making.

Ultimately, MRI remains an invaluable tool in the diagnosis and management of developmental delay, but its findings must be integrated with clinical assessment, genetic testing, and neurodevelopmental evaluations for optimal patient care.

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