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Magnetic Resonance Imaging in Neonatal Hypoxic–Ischemic Encephalopathy: Imaging Patterns and Prognostic Significance – A Retrospective Observational Study

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ABSTRACT

Background: Neonatal hypoxic–ischemic encephalopathy (HIE) is a major cause of neonatal mortality and long-term neurodevelopmental disability. Magnetic resonance imaging (MRI) plays a crucial role in early detection of brain injury and prognostication.
Objective: To evaluate MRI brain findings in term neonates with HIE and to assess imaging patterns and their prognostic significance.
Materials and Methods: This retrospective observational study was conducted in the Department of Radiodiagnosis in collaboration with the Department of Pediatrics and Neonatology at Sri Siddhartha Medical College, Tumakuru, over a period of six months from October 2025 to March 2026. A total of 30 term neonates with clinically diagnosed HIE who underwent MRI brain examination were included. MRI was performed using a 1.5 Tesla scanner with standard sequences including T1WI, T2WI, DWI, ADC, and SWI. Imaging findings were analyzed for pattern of injury, severity, and correlation with clinical outcomes.
Results: Out of 30 neonates, 60% were males. Moderate HIE (Stage II) was most common (50%). The most frequent MRI abnormalities were basal ganglia involvement (46.7%), thalamic involvement (40%), and PLIC involvement (36.7%). The most common imaging pattern was basal ganglia–thalamus pattern (40%), followed by watershed pattern (26.7%), mixed pattern (20%), and diffuse/global injury (13.3%). Severe MRI abnormalities were associated with unfavorable outcomes in 87.5% of cases, whereas mild abnormalities showed favorable outcomes in 88.9%. Diffuse and basal ganglia–thalamus patterns were strongly associated with poor prognosis.
Conclusion: MRI is a valuable imaging modality for evaluating neonatal HIE. Specific MRI patterns, particularly basal ganglia–thalamus and diffuse injury, are strongly associated with adverse neurodevelopmental outcomes. MRI plays an important role in early prognostication and clinical decision-making.

Keywords *Neonatal HIE, MRI, Hypoxic–ischemic encephalopathy, Basal ganglia, Prognosis, DWI.*

INTRODUCTION

Neonatal hypoxic–ischemic encephalopathy (HIE) is a serious perinatal neurological condition caused by reduced oxygen and blood supply to the brain around the time of birth. It remains one of the leading causes of neonatal mortality and long-term neurodevelopmental disability worldwide. The global incidence of HIE ranges from 1–8 per 1,000 live births, with a higher burden in developing countries due to limited access to optimal intrapartum monitoring and neonatal intensive care facilities [1].

The pathophysiology of HIE is complex and involves primary energy failure followed by secondary neuronal injury mediated by excitotoxicity, oxidative stress, inflammation, and apoptosis. The pattern of brain injury depends on the severity and duration of hypoxia–ischemia, gestational maturity, and timing of reperfusion. In term neonates, selective vulnerability is typically seen in metabolically active regions such as the basal ganglia, thalami, perirolandic cortex, and posterior limb of the internal capsule (PLIC), while prolonged partial hypoxia preferentially affects watershed cortical regions [2].

Magnetic resonance imaging (MRI) is the most sensitive neuroimaging modality for evaluating neonatal HIE. It provides excellent anatomical detail and, with diffusion-weighted imaging (DWI), allows early detection of cytotoxic edema even within the first few days of injury. MRI also plays a crucial role in defining the pattern and severity of brain injury and is widely used for prognostication of neurodevelopmental outcomes [3].

Different MRI patterns have been well described in neonatal HIE, including basal ganglia–thalamus pattern, watershed pattern, mixed injury, and diffuse/global injury. These patterns reflect different types of hypoxic insult and are strongly associated with clinical outcomes. Basal ganglia–thalamus injury is commonly linked to acute profound hypoxia and poor motor outcome, whereas watershed injury is associated with prolonged partial hypoxia and relatively better motor prognosis but possible cognitive impairment [4,5].

Therefore, the present study was conducted to evaluate MRI brain findings in term neonates with hypoxic–ischemic encephalopathy and to assess the association between imaging patterns, severity of injury, and clinical outcomes.

MATERIALS AND METHODS

Study Design and Setting

This retrospective observational study was conducted in the Department of Radiodiagnosis in collaboration with the Department of Pediatrics and Neonatology at Sri Siddhartha Medical College, Tumakuru, Karnataka, India. The study was carried out over a period of six months from October 2025 to March 2026 after obtaining approval from the Institutional Ethics Committee.

Study Population

A total of 30 term neonates diagnosed clinically with hypoxic–ischemic encephalopathy (HIE) and who underwent magnetic resonance imaging (MRI) of the brain during the study period were included in the analysis.

Inclusion Criteria

- Term neonates (gestational age ≥37 weeks).
- Clinical diagnosis of neonatal hypoxic–ischemic encephalopathy based on perinatal history and neurological examination.
- Availability of complete MRI brain studies performed within the neonatal period.
- Availability of relevant clinical and follow-up data.

Exclusion Criteria

- Preterm neonates (<37 weeks gestational age).
- Neonates with congenital brain malformations.
- Neonates with metabolic disorders, chromosomal abnormalities, or central nervous system infections.
- Cases with incomplete clinical records or inadequate MRI studies.

Data Collection

Clinical records were reviewed to obtain demographic and perinatal data including gestational age, birth weight, sex, mode of delivery, Apgar scores, need for resuscitation at birth, seizure history, and Sarnat staging of HIE. Relevant laboratory investigations and neonatal outcomes were also recorded.

MRI Protocol

MRI examinations were performed using a 1.5 Tesla MRI scanner. Standard imaging sequences included:

- T1-weighted imaging (T1WI)
- T2-weighted imaging (T2WI)
- Fluid-Attenuated Inversion Recovery (FLAIR), where applicable
- Diffusion-Weighted Imaging (DWI)

- Apparent Diffusion Coefficient (ADC) mapping
- Susceptibility-Weighted Imaging (SWI)

Images were reviewed independently by experienced radiologists blinded to clinical outcomes.

Imaging Assessment

MRI findings were analyzed for the presence and distribution of abnormalities involving:

- Basal ganglia and thalami
- Posterior limb of the internal capsule (PLIC)
- Perirolandic cortex
- Watershed cortical regions
- Subcortical white matter
- Corpus callosum
- Brainstem
- Cerebellum

The imaging patterns were categorized into:

1. Basal ganglia-thalamus pattern
2. Watershed pattern
3. Mixed pattern
4. Diffuse/global injury pattern

The severity of injury was graded as mild, moderate, or severe based on the extent of involvement observed on MRI.

Outcome Assessment

Clinical outcomes were assessed through neonatal records and follow-up evaluations where available. Outcomes were categorized as:

- Favourable outcome (normal neurological examination or mild deficits)
- Unfavourable outcome (developmental delay, cerebral palsy, persistent seizures, or death)

Associations between MRI findings and clinical outcomes were evaluated.

Statistical Analysis

Data were entered into Microsoft Excel and analysed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. The Chi-square test or Fisher's exact test was used to assess associations between imaging findings and clinical outcomes. A p-value of <0.05 was considered statistically significant.

Ethical Considerations

The study was conducted in accordance with the principles of the Declaration of Helsinki. Approval was obtained from the Institutional Ethics Committee of Sri Siddhartha Medical College. Patient confidentiality was maintained throughout the study, and all data were anonymised before analysis.

RESULTS AND OBSERVATIONS

A total of 30 term neonates with clinically diagnosed hypoxic–ischemic encephalopathy (HIE) who underwent MRI brain examination were included in the study. The demographic characteristics, MRI findings, patterns of brain injury, and clinical outcomes were analyzed.

Table 1. Demographic Characteristics of the Study Population (n=30)

Variable	Number (%)
Sex	
Male	**18 (60.0)**
Female	**12 (40.0)**
Gestational Age	
37–38 weeks	**11 (36.7)**
39–40 weeks	**15 (50.0)**
>40 weeks	**4 (13.3)**
Birth Weight	
<2.5 kg	**7 (23.3)**
2.5–3.5 kg	**19 (63.3)**
>3.5 kg	**4 (13.3)**

The majority of neonates were males (60%) and had a gestational age between 39 and 40 weeks (50%).

Table 2. Distribution of HIE Severity According to Sarnat Staging

HIE Stage	Number (%)
Stage I (Mild)	8 (26.7)
Stage II (Moderate)	15 (50.0)
Stage III (Severe)	7 (23.3)
Total	30 (100)

Moderate HIE (Stage II) was the most common clinical presentation, accounting for 50% of cases.

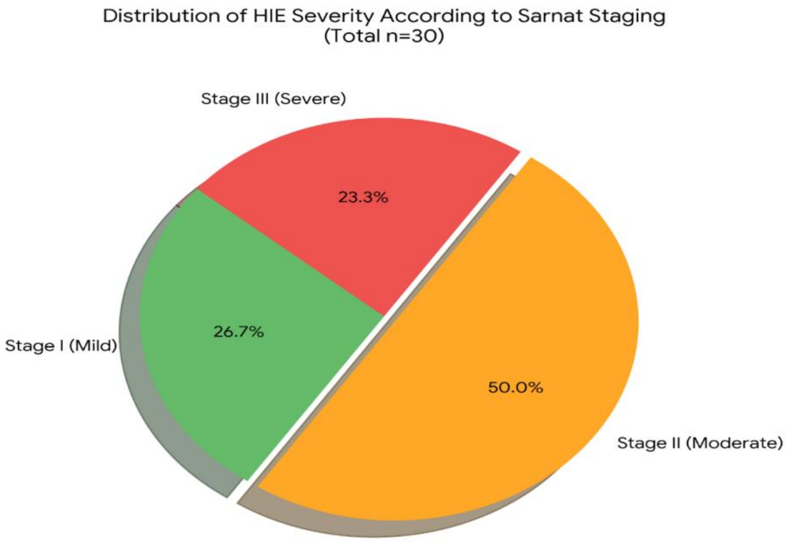

Table 3. MRI Abnormalities Observed in Neonates with HIE

MRI Finding	Number (%)
Basal ganglia involvement	14 (46.7)
Thalamic involvement	12 (40.0)
Watershed cortical injury	10 (33.3)
Subcortical white matter injury	9 (30.0)
Posterior limb of internal capsule (PLIC) involvement	11 (36.7)
Corpus callosum abnormalities	5 (16.7)
Brainstem involvement	4 (13.3)
Cerebellar involvement	2 (6.7)

Basal ganglia involvement was the most frequently observed MRI abnormality, followed by thalamic injury and watershed cortical changes.

Table 4. Distribution of MRI Injury Patterns

MRI Pattern	Number (%)
Basal ganglia-thalamus pattern	12 (40.0)
Watershed pattern	8 (26.7)
Mixed pattern	6 (20.0)
Diffuse/global injury pattern	4 (13.3)
Total	30 (100)

The basal ganglia-thalamus pattern was the predominant MRI injury pattern observed.

Table 5. Severity of MRI Findings

MRI Severity	Number (%)
Mild	9 (30.0)
Moderate	13 (43.3)
Severe	8 (26.7)
Total	30 (100)

Moderate MRI abnormalities constituted the largest group (43.3%).

Table 6. Clinical Outcome in Relation to MRI Severity

MRI Severity	Favorable Outcome n (%)	Unfavorable Outcome n (%)
Mild (n=9)	8 (88.9)	1 (11.1)
Moderate (n=13)	8 (61.5)	5 (38.5)
Severe (n=8)	1 (12.5)	7 (87.5)
Total (n=30)	17 (56.7)	13 (43.3)

A significant increase in unfavorable outcomes was observed with increasing MRI severity. Severe MRI abnormalities were associated with poor neurological outcomes in 87.5% of neonates.

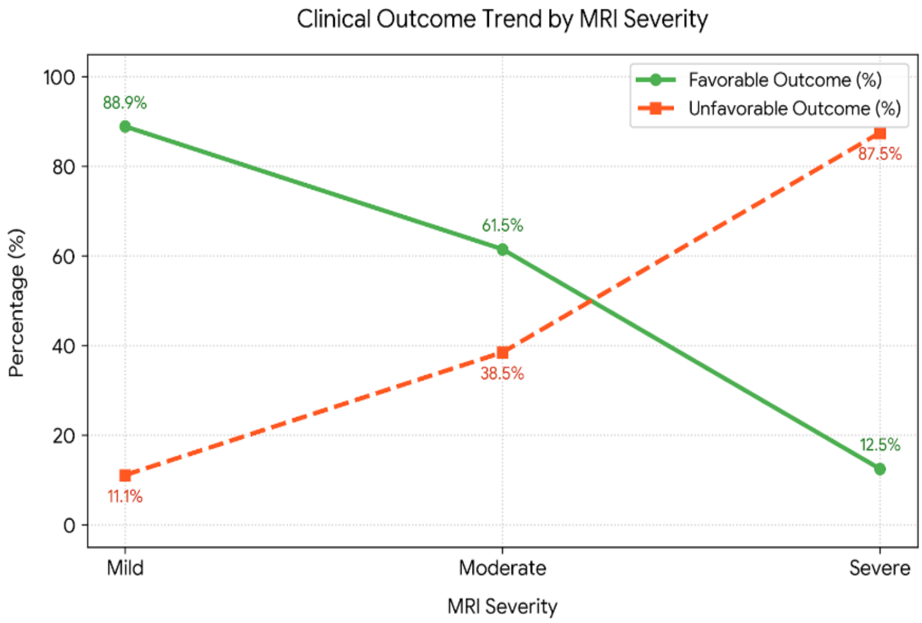

Table 7. Association Between MRI Injury Pattern and Clinical Outcome

MRI Pattern	Favorable Outcome	Unfavorable Outcome
Basal ganglia-thalamus	4	8
Watershed pattern	7	1
Mixed pattern	4	2
Diffuse/global injury	0	4
Total	15	15

Diffuse/global injury and basal ganglia-thalamus injury patterns showed the highest association with adverse neurological outcomes, whereas watershed injury was associated with comparatively better prognosis.

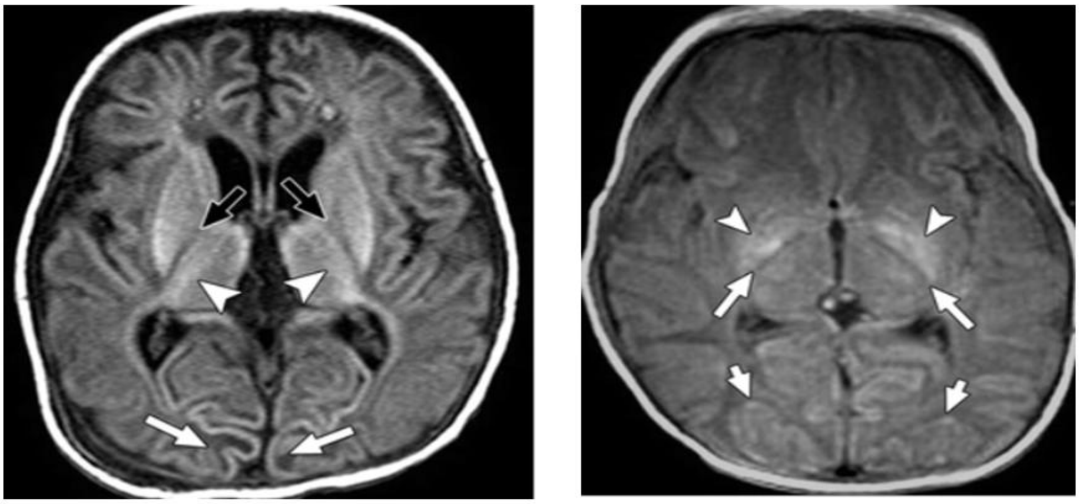

Figure A & B

Figure A: Axial T1-weighted image in 5-day-old full-term girl with severe, total hypoxia. Hyperintense signal is present in both basal ganglia and thalami (arrowheads), indicating deep gray matter hypoxia. Whereas posterior limb of internal capsule on this pulse sequence is normally hyperintense relative to basal ganglia and thalamus, in this infant it is hypointense.

Figure B: 4-day-old full-term girl with severe, total hypoxia and persistent seizures. This case also shows some features of partial, prolonged hypoxia pattern. Unenhanced axial T1-weighted image shows absence of normal bright signal in posterior limb of internal capsule (long arrows), referred to as “absent posterior limb sign.” In addition, abnormal increased signal intensity is seen in basal ganglia (arrowheads). Both findings are typical of severe, total hypoxia pattern. Relative increase in signal intensity in posterior putamen relative to posterior limb of internal capsule is reported to be one of most sensitive signs of neonatal hypoxia . Curvilinear regions of increased signal intensity in occipital lobes (short arrows) indicate cortical injury, which is typically seen in partial, prolonged hypoxia pattern.

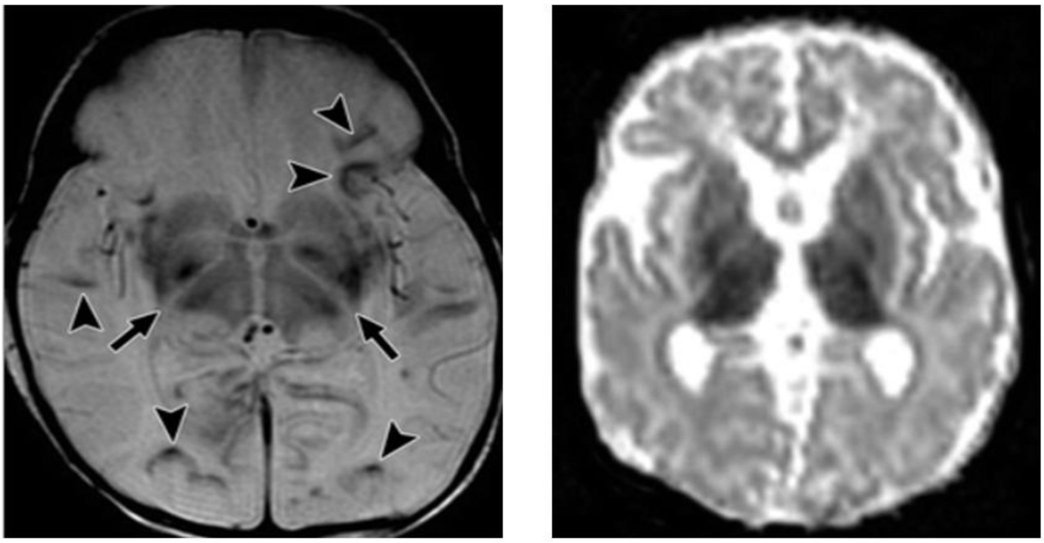

Figure C & D

Figure C:4-day-old full-term girl with severe, total hypoxia and persistent seizures. This case also shows some features of partial, prolonged hypoxia pattern. Axial T2-weighted image shows absence of normal hypointense signal in posterior limb of internal capsule (arrows). Regions of diminished signal intensity in brain cortex (arrowheads), corresponding to cortical findings.

Figure D: Restricted diffusion in basal ganglia and thalamus noted bilaterally

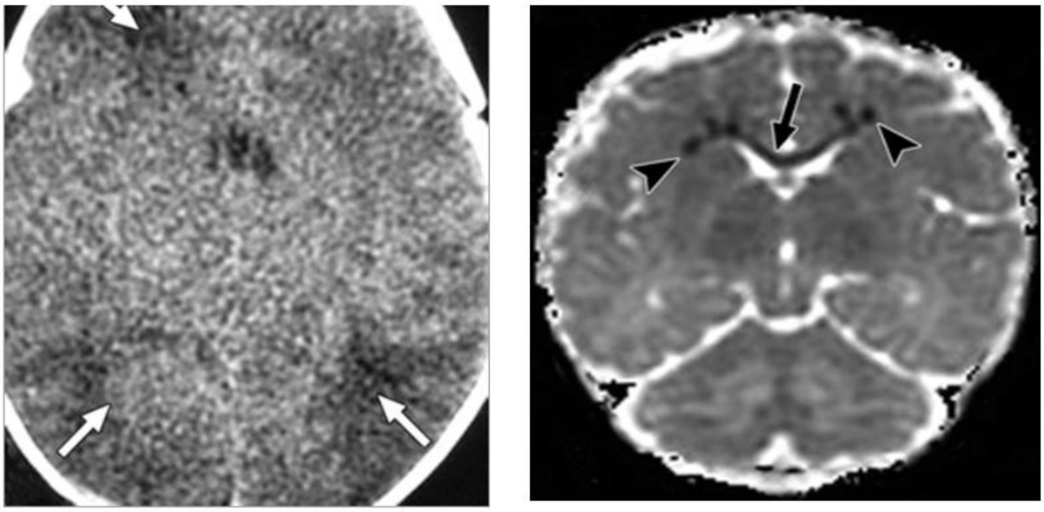

Figure E&F

Figure E: Unenhanced axial CT scan in 3-day-old full-term boy with hypoperfusion injury. Low-density regions indicating watershed ischemia (arrows) are seen in parietooccipital regions (long arrows) and in right frontal lobe (short arrow).

Figure F: Axial proton density-weighted image in 11-day old full-term girl with severe hypoperfusion. Coronal apparent diffusion coefficient map shows foci of restricted diffusion.

DISCUSSION

Neonatal hypoxic–ischemic encephalopathy continues to be a major cause of neonatal morbidity and mortality. MRI plays a pivotal role in early diagnosis and prognostication by identifying specific patterns of brain injury and correlating them with clinical outcomes.

Demographic and Clinical Profile

In the present study, male neonates constituted 60% of cases (Table 1). This male predominance is consistent with previous studies suggesting greater susceptibility of male neonates to hypoxic–ischemic injury due to differences in neuroprotective hormonal mechanisms and apoptotic pathways [6]. Most neonates were term and appropriately grown, which aligns with the known epidemiology that HIE primarily affects term infants following perinatal asphyxial events.
Moderate HIE (Sarnat Stage II) was the most common clinical presentation (50%) (Table 2). This finding is consistent with Rutherford et al., who reported that moderate encephalopathy represents the largest proportion of cases referred for MRI evaluation, as these infants survive initial insult and undergo imaging for prognostic assessment [7].

MRI Brain Abnormalities

In the present study, basal ganglia involvement was the most frequent MRI abnormality (46.7%), followed by thalamic involvement (40%) and PLIC involvement (36.7%) (Table 3). These findings reflect the high metabolic demand and selective vulnerability of deep gray matter structures during acute hypoxic insults.

Similar observations have been reported by Barkovich et al., who described basal ganglia and thalami as key regions affected in acute profound HIE [8]. PLIC involvement is particularly important as it is a strong predictor of motor outcome and later development of cerebral palsy.

Watershed cortical injury was observed in 33.3% of cases, indicating a significant proportion of prolonged partial hypoxic injury in the cohort.

MRI Injury Patterns

The most common MRI pattern in this study was the basal ganglia–thalamus pattern (40%), followed by watershed (26.7%), mixed (20%), and diffuse/global injury (13.3%) (Table 4).

This distribution is consistent with Martinez-Biarge et al., who reported that basal ganglia–thalamus injury is typical of acute profound hypoxia, whereas watershed injury is more commonly associated with partial prolonged hypoxia [5]. The relatively lower proportion of diffuse injury may be due to early neonatal mortality or limited referral for MRI in the most severe cases.

MRI Severity and Clinical Outcome

A strong relationship was observed between MRI severity and clinical outcome (Table 6). Among neonates with severe MRI abnormalities, 87.5% had unfavorable outcomes, whereas 88.9% of neonates with mild MRI findings had favorable outcomes.

This demonstrates a clear dose-dependent relationship between extent of brain injury and neurological outcome. Similar findings were reported by Weeke et al., who demonstrated that MRI-based scoring systems are strong predictors of neurodevelopmental outcome after perinatal asphyxia [9].

MRI Pattern and Outcome Correlation

The basal ganglia–thalamus pattern showed a strong association with unfavorable outcome (8/12 cases), reflecting severe involvement of motor control pathways.

In contrast, the watershed pattern showed relatively better prognosis, with most cases (7/8) showing favorable outcome (Table 7). This aligns with Miller et al., who reported that watershed injury is more commonly associated with cognitive and behavioral deficits rather than severe motor impairment [10].

Diffuse/global injury showed universally poor outcomes (100% unfavorable), confirming its status as the most severe MRI pattern associated with high risk of death or severe disability.

Clinical Implications

The present study highlights the importance of MRI in early prognostication of neonatal HIE. Identification of injury patterns such as basal ganglia–thalamus involvement, PLIC injury, and diffuse cerebral injury helps in predicting outcome, guiding parental counseling, and planning early neurodevelopmental intervention.

MRI findings also complement clinical staging systems such as Sarnat staging, improving overall diagnostic and prognostic accuracy.

Limitations

The limitations of this study include small sample size, single-center design, and lack of long-term neurodevelopmental follow-up. Additionally, timing of MRI acquisition may influence detection of diffusion abnormalities, potentially affecting classification of injury patterns.

CONCLUSION

MRI is a highly valuable tool in the evaluation of neonatal HIE. There is a strong correlation between MRI injury patterns, severity of brain involvement, and clinical outcomes. Basal ganglia–thalamus and diffuse injury patterns are associated with poor prognosis, whereas watershed injury shows relatively better outcomes.

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