

Predictors of Postoperative and Neurodevelopmental Outcomes in Children with Hydrocephalus from Tribal and Low-Socioeconomic Populations

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Abstract

Background: Pediatric hydrocephalus is associated with considerable postoperative and neurodevelopmental morbidity, particularly among children from tribal and socioeconomically disadvantaged communities where delayed presentation and limited access to specialized care may adversely influence outcomes. This study evaluated postoperative and neurodevelopmental outcomes and their potential predictors in this vulnerable population. **Material and Methods:** This hospital-based prospective observational study included 25 children with hydrocephalus from predominantly tribal and low-socioeconomic backgrounds who underwent surgical management. Demographic, socioeconomic, clinical, etiological, radiological, surgical, and follow-up characteristics were recorded. Postoperative and neurodevelopmental outcomes were assessed, and factors associated with unfavourable outcomes were analyzed using SPSS. 21. statistical tests. **Results:** The mean age was 3.8 ± 3.2 years; 60.0% were males, 72.0% belonged to tribal communities, and 84.0% had low socioeconomic status. Delayed presentation occurred in 56.0%, developmental delay in 52.0%, and severe ventricular dilatation in 48.0%. VP shunting was performed in 100.0%. Postoperative complications occurred in 4.0%, while 4.0% had unfavourable postoperative outcomes and 44.0% had unfavourable neurodevelopmental outcomes. Delayed presentation, post-infectious/post-hemorrhagic etiology, seizures, malnutrition, severe ventricular dilatation, and distance >50 km were significantly associated with unfavourable postoperative outcomes. Unfavourable neurodevelopment was associated with baseline developmental delay (OR 11.25), structural brain abnormalities (OR 10.50), limited rehabilitation access (OR 9.78), delayed presentation (OR 8.10), seizures and postoperative complications (OR 7.20 each), and malnutrition (OR 6.42). **Conclusion:** Outcomes of childhood hydrocephalus in disadvantaged populations were influenced by clinical severity and healthcare-access barriers. Early referral, timely surgery, nutritional optimization, structured follow-up, and accessible neurodevelopmental rehabilitation may improve outcomes.

Keywords: Pediatric hydrocephalus; neurodevelopmental outcome; ventriculoperitoneal shunt; tribal population; socioeconomic status; postoperative outcome; developmental delay.

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INTRODUCTION

Pediatric hydrocephalus is a major neurosurgical condition characterized by abnormal accumulation of cerebrospinal fluid (CSF) within the ventricular system, resulting in progressive ventricular dilatation and, frequently, raised intracranial pressure. When occurring during infancy and early childhood, hydrocephalus can interfere with critical periods of brain growth and maturation, leading to developmental delay, cognitive impairment, motor disability, seizures, visual dysfunction, and other long-term neurological sequelae.^[1,2] Early diagnosis and appropriate neurosurgical intervention are therefore essential for preventing irreversible neurological injury and improving functional outcomes. The etiology of childhood hydrocephalus is heterogeneous and includes congenital aqueductal stenosis, neural tube defects, intraventricular hemorrhage (IVH), central nervous system infections, intracranial tumors, and other developmental abnormalities. Outcomes vary considerably according to the underlying

etiology, age at onset, severity and duration of ventricular enlargement, associated structural brain abnormalities, and neurological comorbidities.^[3-7] Post-hemorrhagic hydrocephalus following IVH of prematurity is of particular concern because ventricular distension, raised intracranial pressure, oxidative stress, inflammation, and iron-mediated toxicity from blood degradation products may collectively contribute to injury of the developing brain.^[8,9] Prematurity itself further increases the risk of cerebral palsy, epilepsy, visual

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impairment, and adverse neurodevelopmental outcomes.^[10-13]

Ventriculoperitoneal (VP) shunting remains a commonly used treatment for pediatric hydrocephalus, while endoscopic third ventriculostomy, with or without choroid plexus cauterization, provides an alternative in selected patients. Despite effective CSF diversion, postoperative complications such as shunt obstruction, infection, CSF leakage, over- or under-drainage, and repeated revision procedures remain important causes of morbidity. Premature infants may be especially susceptible to shunt complications because of immune immaturity, elevated CSF protein concentrations, and residual intraventricular blood products.^[14] Consequently, treatment success should be assessed not merely through shunt survival or revision rates but also through long-term motor, cognitive, language, adaptive, and social development.

These challenges may be amplified among children from tribal and socioeconomically disadvantaged populations. Geographic isolation, financial constraints, low parental literacy, inadequate awareness, poor transportation, and limited access to specialized pediatric neurosurgical and rehabilitation services may contribute to delayed presentation and treatment. Following surgery, difficulties with regular follow-up and access to physiotherapy, developmental assessment, and early-intervention services may further adversely influence outcomes. Postoperative and neurodevelopmental outcomes in childhood hydrocephalus therefore represent the cumulative effects of clinical, etiological, surgical, developmental, and socioeconomic determinants. However, evidence regarding these predictors among tribal and low-socioeconomic populations remains limited. The present study aims to identify predictors of postoperative and neurodevelopmental outcomes in children with hydrocephalus from tribal and low-socioeconomic populations.

MATERIALS AND METHODS

This hospital-based, prospective observational study was conducted in the Department of Neurosurgery at a tertiary care hospital catering to a substantial tribal and socioeconomically disadvantaged population. The study was designed to evaluate the clinical, surgical, socioeconomic, and healthcare-related factors associated with postoperative and neurodevelopmental outcomes among children undergoing surgical treatment for hydrocephalus.

Study Population: The study population comprised children diagnosed with hydrocephalus who belonged predominantly to tribal and/or low-socioeconomic backgrounds and underwent surgical treatment at the study institution. Hydrocephalus was diagnosed on the basis of clinical examination and appropriate neuroimaging findings.

Sample Size: A total of 25 children with hydrocephalus who fulfilled the eligibility criteria were included in the study. All eligible patients presenting during the defined study period were consecutively enrolled until the required

sample size was achieved.

Sampling Technique: A consecutive sampling technique was used. Children satisfying the predefined inclusion and exclusion criteria were recruited after obtaining informed consent from their parents or legal guardians.

Inclusion Criteria: Children with clinically and radiologically confirmed hydrocephalus who underwent surgical intervention at the study centre were included. Children belonging to tribal communities and/or low-socioeconomic groups, whose parents or legal guardians provided informed consent and who were available for postoperative follow-up and neurodevelopmental assessment, were considered eligible.

Exclusion Criteria: Children whose parents or legal guardians declined consent, those with incomplete clinical or follow-up information, and children who could not undergo adequate postoperative or neurodevelopmental assessment were excluded from the final analysis.

Data Collection: Demographic, socioeconomic, clinical, radiological, operative, and follow-up information was recorded using a predesigned structured data collection form. Demographic characteristics included age, sex, place of residence, tribal status, parental education, socioeconomic status, and distance from the treating healthcare facility.

Clinical variables included age at onset and diagnosis of hydrocephalus, duration of symptoms before presentation, presenting manifestations, head circumference, neurological status, nutritional status, seizures, developmental delay, associated congenital abnormalities, and relevant comorbidities. Etiology of hydrocephalus was categorized according to clinical and radiological findings as congenital, post-infectious, post-hemorrhagic, tumor-related, or other causes.

Radiological Assessment: All children underwent appropriate neuroimaging using ultrasonography, computed tomography, and/or magnetic resonance imaging, depending on age and clinical requirements. Ventricular dilatation, site of obstruction, associated structural abnormalities, evidence of previous hemorrhage or infection, and other relevant intracranial findings were documented.

Surgical Management: The choice of surgical procedure was based on the etiology of hydrocephalus, age of the child, anatomical characteristics, clinical condition, and treating neurosurgeon's assessment. Children underwent ventriculoperitoneal (VP) shunt placement. Operative details and perioperative events were documented.

Assessment of Postoperative Outcomes: Patients were monitored during hospitalization and subsequently during scheduled follow-up visits. Postoperative outcomes included duration of hospital stay, wound-related complications, CSF leakage, shunt infection, shunt obstruction or malfunction, over-drainage or under-drainage, postoperative seizures, neurological deterioration, requirement for readmission, revision surgery, and mortality.

The requirement for shunt revision or repeat CSF diversion procedure during follow-up was recorded. Postoperative outcomes were categorized as favourable or unfavourable according to predefined clinical and surgical outcome criteria.

Neurodevelopmental Assessment: Neurodevelopment was assessed during follow-up using an age-appropriate standardized developmental assessment method. Major

developmental domains, including gross motor, fine motor, language, cognitive, personal-social, and adaptive functioning, were evaluated wherever applicable.

Children were classified according to the presence or absence and severity of developmental delay. Neurological sequelae, including cerebral palsy, epilepsy, motor impairment, visual abnormalities, and other persistent neurological deficits, were also documented.

Assessment of Socioeconomic and Healthcare-Access

Factors: Socioeconomic and healthcare-access variables were specifically evaluated because of the study population. These included parental education, family socioeconomic status, tribal residence, distance from the healthcare facility, transportation difficulties, financial constraints, delay in seeking medical care, availability of specialist services, adherence to scheduled follow-up, and access to physiotherapy and developmental rehabilitation services. Delay in presentation and treatment was documented wherever applicable to determine whether restricted healthcare access influenced postoperative or neurodevelopmental outcomes.

Assessment of Predictors: Potential predictors were grouped into demographic, socioeconomic, clinical, etiological, radiological, surgical, and follow-up-related factors. Their associations with postoperative complications and neurodevelopmental outcomes were subsequently examined. Particular emphasis was placed on potentially modifiable factors, including delayed presentation, nutritional status, postoperative infection, treatment-related complications, poor follow-up, and limited access to rehabilitation.

Outcome Measures: The primary outcomes were postoperative surgical outcome and neurodevelopmental status during follow-up. Postoperative complications, shunt failure/revision, neurological morbidity, and mortality were assessed as surgical outcomes.

The secondary outcomes included identification of demographic, clinical, etiological, socioeconomic, healthcare-access, and treatment-related factors associated with unfavourable postoperative or neurodevelopmental outcomes.

Statistical Analysis: Data were entered into a computerized

database and analyzed using SPSS.26statistical software. Continuous variables were expressed as mean $\pm$ standard deviation (SD) or median with interquartile range (IQR) according to the distribution of data. Categorical variables were presented as frequencies and percentages.

Associations between categorical variables and postoperative or neurodevelopmental outcomes were evaluated using the Chi-square test or Fisher's exact test, as appropriate. Continuous variables were compared using the independent-samples t-test or Mann-Whitney U test, depending on data distribution. Potential predictors of unfavourable outcomes were explored using appropriate regression analysis wherever permitted by the number of outcome events. Considering the relatively small sample size (n=25), multivariable modelling was interpreted cautiously to avoid model overfitting. A p-value <0.05 was considered statistically significant.

RESULTS

A total of 25 children with hydrocephalus were evaluated for demographic, socioeconomic, clinical, radiological, surgical, postoperative, and neurodevelopmental characteristics. The mean age was 3.8 ± 3.2 years; 44.0% were aged 1–5 years, while 28.0% each were aged <1 year and >5 years. Males constituted 60.0% of the cohort. Most children belonged to vulnerable populations: 72.0% were from tribal communities, 80.0% resided in rural/remote areas, and 84.0% belonged to a low socioeconomic group. Financial constraints were reported by 68.0%, transportation/access difficulties by 60.0%, and 56.0% lived >50 km from the treatment centre [Table 1].

Delayed presentation occurred in 56.0% of children. Increased head circumference was the most common presentation (72.0%), followed by developmental delay (52.0%), vomiting/irritability (44.0%), malnutrition (40.0%), and seizures (32.0%). Congenital hydrocephalus/aqueductal stenosis was the most frequent etiology (32.0%), followed by post-infectious (28.0%) and post-hemorrhagic hydrocephalus (16.0%). Structural brain abnormalities were present in 36.0%, and severe ventricular dilatation in 48.0% [Table 2; Figure 1]. VP shunting was performed in 100% of children. Mortality was 4.0%. Overall, postoperative outcome was Favourable in 68.0% and unfavourable in 32.0% [Table 3].

Table 1: Demographic and socioeconomic characteristics of the study participants (n=25)

Variable	Value
Age (years), mean $\pm$ SD	3.8 $\pm$ 3.2
Age group, n (%)	
<1 year	7 (28.0)
1–5 years	11 (44.0)
>5 years	7 (28.0)
Sex, n (%)	
Male	15 (60.0)
Female	10 (40.0)
Tribal population	18 (72.0)
Rural/remote residence	20 (80.0)
Low socioeconomic status	21 (84.0)
Parental education $\leq$ primary level	16 (64.0)
Distance from treatment centre >50 km	14 (56.0)
Financial constraints reported	17 (68.0)
Difficulty in transportation/access	15 (60.0)

Table 2: Clinical, etiological and radiological characteristics of children with hydrocephalus (n=25)

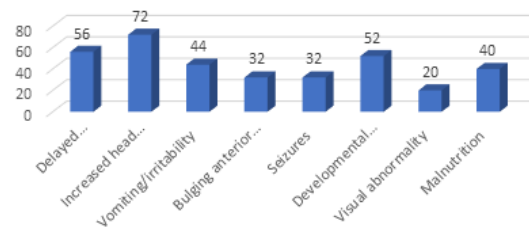
Variable	n (%)
Delayed presentation	14 (56.0)
Increased head circumference	18 (72.0)
Vomiting/irritability	11 (44.0)
Bulging anterior fontanelle*	8 (32.0)
Seizures	8 (32.0)
Developmental delay at presentation	13 (52.0)
Visual abnormality	5 (20.0)
Malnutrition	10 (40.0)
Etiology of hydrocephalus	
Congenital/aqueductal stenosis	8 (32.0)
Post-infectious	7 (28.0)
Post-hemorrhagic	4 (16.0)
Neural tube defect-associated	3 (12.0)
Tumor-related/other	3 (12.0)
Associated structural brain abnormality	9 (36.0)
Severe ventricular dilatation	12 (48.0)

At follow-up, 56.0% demonstrated age-appropriate development, whereas 44.0% had developmental delay. Gross motor (36.0%), language (32.0%), cognitive (28.0%), and multiple-domain (28.0%) delays were common. Persistent epilepsy/seizures occurred in 20.0%, cerebral palsy/motor impairment in 16.0%, and visual impairment in 12.0%. Overall, neurodevelopmental outcome was favourable in 56.0% and unfavourable in 44.0% [Table 4; Figure 2].

Unfavourable postoperative outcomes were significantly associated with delayed presentation (87.5% vs. 41.2%; $p=0.04$), post-infectious/post-hemorrhagic etiology (75.0% vs. 29.4%; $p=0.04$), seizures at presentation (62.5% vs. 17.6%; $p=0.03$), malnutrition (75.0% vs. 23.5%; $p=0.03$), severe ventricular dilatation (87.5% vs. 29.4%; $p=0.01$), and distance >50 km from the treatment centre (87.5% vs. 41.2%; $p=0.04$) [Table 5; Figure 3].

Significant predictors of unfavourable neurodevelopment included delayed presentation (OR 8.10, 95% CI 1.30–50.6; $p=0.04$), developmental delay at presentation (OR 11.25, 95% CI 1.65–76.8; $p=0.01$), seizures (OR 7.20, 95% CI 1.08–48.0; $p=0.04$), structural brain abnormalities (OR 10.50, 95% CI 1.55–71.0; $p=0.02$), malnutrition (OR 6.42, 95% CI 1.08–38.3; $p=0.04$), postoperative complications (OR 7.20, 95% CI 1.08–48.0; $p=0.04$), and limited rehabilitation access (OR 9.78, 95% CI 1.54–62.0; $p=0.02$) [Table 6].

Clinical, etiological and radiological characteristics of children with hydrocephalus (n=25)



Etiology of hydrocephalus

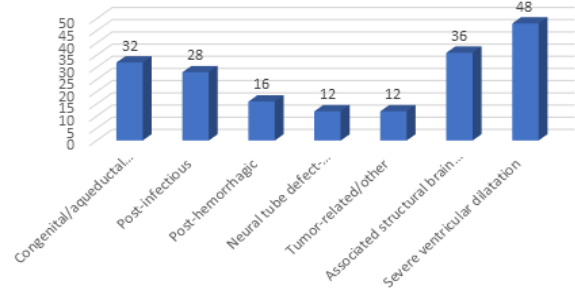


Figure 1: Clinical, etiological and radiological characteristics of children with hydrocephalus (n=25).

Table 3: Surgical management and postoperative outcomes (n=25)

Variable	Value
Surgical procedure, n (%)	
VP shunt	25 (100)
Duration of hospital stay (days), mean $\pm$ SD	8.4 $\pm$ 3.6
Mortality	1 (4.0)
Overall postoperative outcome	
Favourable	24 (96.0)
Unfavourable	1 (4.0)

Table 4: Neurodevelopmental outcomes during follow-up (n=25)

Neurodevelopmental outcome	n (%)
Age-appropriate overall development	14 (56.0)
Any developmental delay	11 (44.0)
Gross motor delay	9 (36.0)
Fine motor delay	6 (24.0)

Language delay	8 (32.0)
Cognitive delay	7 (28.0)
Personal-social/adaptive delay	6 (24.0)
Multiple-domain developmental delay	7 (28.0)
Cerebral palsy/motor impairment	4 (16.0)
Epilepsy/persistent seizures	5 (20.0)
Visual impairment	3 (12.0)
Overall neurodevelopmental outcome	
Favourable	14 (56.0)
Unfavourable	11 (44.0)

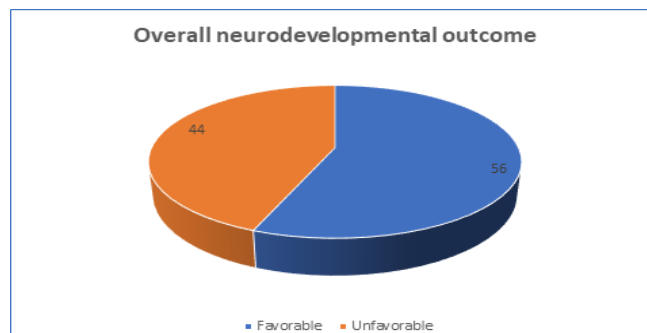
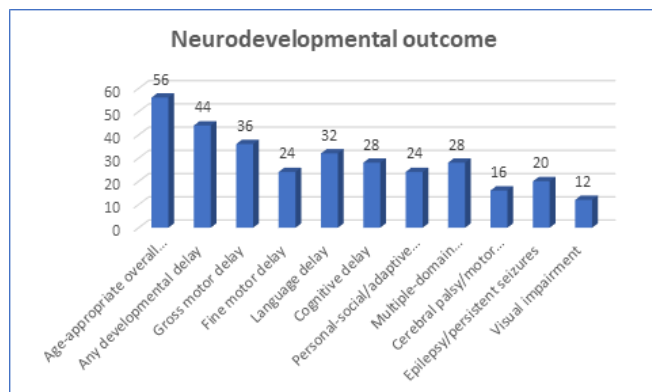


Figure 2: Neurodevelopmental outcomes during follow-up (n=25).

Table 5: Factors associated with unFavourable postoperative outcome (n=25)

Potential predictor	Favourable (n=17), n (%)	UnFavourable (n=8), n (%)	p-value
Age <1 year	3 (17.6)	4 (50.0)	0.16
Delayed presentation	7 (41.2)	7 (87.5)	0.04
Post-infectious/post-hemorrhagic etiology	5 (29.4)	6 (75.0)	0.04
Developmental delay at presentation	7 (41.2)	6 (75.0)	0.20
Seizures at presentation	3 (17.6)	5 (62.5)	0.03
Malnutrition	4 (23.5)	6 (75.0)	0.03
Severe ventricular dilatation	5 (29.4)	7 (87.5)	0.01
Distance from treatment centre >50 km	7 (41.2)	7 (87.5)	0.04
Poor/incomplete follow-up	2 (11.8)	4 (50.0)	0.06

Table 6: Factors associated with unFavourable neurodevelopmental outcome (n=25)

Predictor	Favourable NDO (n=14), n (%)	UnFavourable NDO (n=11), n (%)	OR (95% CI)	p-value
Delayed presentation	5 (35.7)	9 (81.8)	8.10 (1.30–50.6)	0.04
Developmental delay at presentation	4 (28.6)	9 (81.8)	11.25 (1.65–76.8)	0.01
Seizures at presentation	2 (14.3)	6 (54.5)	7.20 (1.08–48.0)	0.04
Post-infectious/post-hemorrhagic etiology	4 (28.6)	7 (63.6)	4.38 (0.83–23.2)	0.11
Associated structural brain abnormality	2 (14.3)	7 (63.6)	10.50 (1.55–71.0)	0.02
Malnutrition	3 (21.4)	7 (63.6)	6.42 (1.08–38.3)	0.04
Postoperative complication	2 (14.3)	6 (54.5)	7.20 (1.08–48.0)	0.04
Revision/repeat surgery	1 (7.1)	4 (36.4)	7.43 (0.70–78.6)	0.13
Limited access to rehabilitation	3 (21.4)	8 (72.7)	9.78 (1.54–62.0)	0.02

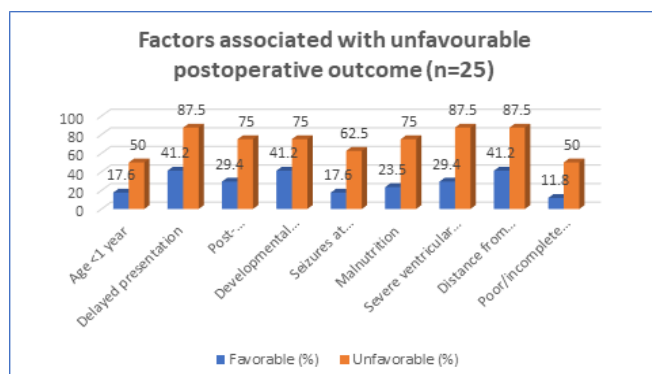


Figure 3: Factors associated with unFavourable postoperative outcome (n=25)

DISCUSSION

The present study evaluated postoperative and neurodevelopmental outcomes in 25 children with hydrocephalus from predominantly tribal and socioeconomically disadvantaged populations. Overall, 96.0% had Favourable postoperative outcomes and 4.0% had unFavourable outcomes, whereas 56.0% had Favourable and 44.0% had unFavourable neurodevelopmental outcomes. These findings suggest that outcomes in childhood hydrocephalus are influenced by disease severity, neurological status at presentation, postoperative complications, and socioeconomic and healthcare-access factors.

The mean age in our study was 3.8 ± 3.2 years, and 60.0% were males. Increased head circumference was the most frequent

presentation (72.0%), followed by developmental delay (52.0%) and seizures (32.0%). Garg et al. (2021),^[15] in a study of 50 children who underwent shunt surgery during infancy, similarly reported male predominance (72%), increasing head size in 88%, vomiting in 30%, and seizures in 20%. They also observed that earlier diagnosis was associated with fewer complications and better developmental outcomes.

Socioeconomic disadvantage was prominent in our cohort, with 72.0% belonging to tribal communities, 80.0% residing in rural/remote areas, 84.0% having low socioeconomic status, and 56.0% living >50 km from the treatment centre. Delayed presentation occurred in 56.0%. Idowu et al. (2024),^[16] studied 100 children aged ≤5 years and demonstrated substantial healthcare-access delays: only 34% sought care, 15% reached care, and 1% received definitive treatment within two weeks. Their findings also demonstrated significant relationships between socioeconomic status and delays in receiving definitive care. In our study, delayed presentation was associated with both unfavourable postoperative outcome (87.5% vs. 41.2%; $p=0.04$) and unfavourable neurodevelopment (81.8% vs. 35.7%; OR 8.10; $p=0.04$).

Congenital/aqueductal stenosis was the most common etiology (32.0%), while post-infectious and post-hemorrhagic hydrocephalus together accounted for 44.0%. Mohamed et al. (2021).^[17] evaluated 323 infants and found post-hemorrhagic hydrocephalus in 31.9%; these children had significantly higher 5-year shunt revision rates, with severe disability increasing to 65.0% at 10 years. Similarly, in our study, post-infectious/post-hemorrhagic etiology was significantly more frequent among children with unfavourable postoperative outcomes (75.0% vs. 29.4%; $p=0.04$).

VP shunting was performed in 100.0% of our children. Postoperative one patient died. Kulkarni et al. (2017),^[18] randomized 100 Ugandan infants with postinfectious hydrocephalus to ETV-CPC or VP shunting and reported treatment failure rates of 35% and 24%, respectively ($p=0.24$), with no significant difference in cognitive, motor, or language outcomes at 12 months.

Neurodevelopmental morbidity remained substantial in our study, with 44.0% having developmental delay, including gross motor delay in 36.0%, language delay in 32.0%, and cognitive delay in 28.0%. Sobana et al. (2021),^[19] in a meta-analysis of 12 studies, found significantly increased risks of cerebral palsy, epilepsy/seizures, sensory impairment, and mental and motor developmental delay among children with shunted non-infectious hydrocephalus, emphasizing the importance of continuous rehabilitation.

The strongest associations with unfavourable neurodevelopment in our study were baseline developmental delay (OR 11.25; $p=0.01$), structural brain abnormalities (OR 10.50; $p=0.02$), limited rehabilitation access (OR 9.78; $p=0.02$), delayed presentation (OR 8.10; $p=0.04$), seizures (OR 7.20; $p=0.04$), postoperative complications (OR 7.20; $p=0.04$), and malnutrition (OR 6.42; $p=0.04$). Collectively, our findings, together with those of Garg et al,^[15] Idowu et al,^[16] Mohamed et al,^[17]

Kulkarni et al,^[18] and Sobana et al,^[19] indicate that improving outcomes requires not only effective CSF diversion but also early diagnosis and referral, nutritional optimization, prevention of postoperative complications, improved access to specialist care, structured follow-up, and long-term neurodevelopmental rehabilitation, particularly for children from tribal and socioeconomically disadvantaged communities.

CONCLUSION

The present study demonstrated that children with hydrocephalus from tribal and socioeconomically disadvantaged populations experienced substantial postoperative and neurodevelopmental morbidity. Delayed presentation, seizures, malnutrition, severe ventricular dilatation, structural brain abnormalities, postoperative complications, and limited access to rehabilitation were important factors associated with unfavourable outcomes. Early diagnosis, timely neurosurgical intervention, nutritional optimization, and effective management of postoperative complications are therefore essential. Improving access to specialist follow-up and long-term neurodevelopmental rehabilitation may further enhance outcomes in these vulnerable children.

Limitations: The study was limited by its small sample size ($n=25$) and single-centre design, which restricted the generalizability of the findings. The relatively short follow-up period may not have captured long-term neurodevelopmental outcomes or late shunt-related complications. The small number of outcome events also limited robust multivariable analysis of independent predictors. Larger multicentre prospective studies with longer follow-up are required to validate these findings.

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Conflicts of interest

There are no conflicts of interest.

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