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Transcranial Ultrasound in Evaluation of Brain Insults in High-Risk Neonates

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Abstract: ***Background: Brain injury in high-risk neonates is a major cause of neonatal morbidity and mortality. Early detection of intracranial abnormalities is essential for timely intervention. Transcranial ultrasound (TCUS) is a bedside, non-invasive, radiation-free imaging modality widely used for neonatal neuroimaging. Objectives: To evaluate the role of transcranial ultrasound in the detection and characterization of brain insults in high-risk neonates and to identify clinical and perinatal predictors of abnormal neurosonographic findings. Methods: This prospective observational study was conducted at a tertiary care teaching hospital that included 100 high-risk neonates admitted to the NICU. All infants underwent transcranial ultrasound through the anterior fontanelle using a standardized imaging protocol. Clinical, demographic, and neurosonographic data were analyzed. Associations between ultrasound findings, gestational age, birth weight, clinical manifestations, and final diagnoses were assessed using chi-square tests, Cramer's V, and multivariable logistic regression. Results: The mean gestational age was 34.81 ± 4.40 weeks and mean birth weight was 2.26 ± 0.70 kg. Abnormal ultrasound findings were detected in 32% of neonates. Ventriculomegaly was present in 12%, periventricular echogenicity in 14%, ventriculitis in 7%, and germinal matrix hemorrhage in 3%. The most common diagnoses were periventricular leukomalacia (8%), hydrocephalus (7%), meningitis (6%), hypoxic ischemic encephalopathy (5%), and germinal matrix hemorrhage (3%). Significant associations were observed between gestational age and ventriculomegaly (p=0.014), gestational age and periventricular echogenicity (p<0.001), ventriculomegaly and hydrocephalus (p<0.001), ventriculitis and meningitis (p<0.001), and caudothalamic echogenicity and germinal matrix hemorrhage (p<0.001). Independent predictors of abnormal ultrasound findings included very preterm birth (AOR 5.8), seizures (AOR 4.6), low birth weight (AOR 2.9), and apnea (AOR 2.4). Conclusion: Transcranial ultrasound is an effective first-line neuroimaging tool for early detection of brain insults in high-risk neonates. Prematurity, low birth weight, seizures, and apnea significantly increase the likelihood of abnormal neurosonographic findings, supporting routine screening in these vulnerable groups.***

Keywords: Transcranial ultrasound, High-risk neonates, Neurosonography, Prematurity, Low birth weight, Ventriculomegaly Hydrocephalus, Neonatal brain injury

1. Introduction

Brain injury in high-risk neonates results from the interaction of multiple physiological vulnerabilities. The immature neonatal brain, particularly in preterm and growth-restricted infants, is characterized by structural immaturity, fragile vascular architecture, high metabolic demands, and limited compensatory reserves. Exposure to hypoxia, ischemia, infection, or hemodynamic instability can lead to characteristic patterns of cerebral injury. [1]

The presence of open fontanelles and sutures provides natural acoustic windows, making transcranial ultrasound an ideal bedside neuroimaging modality in neonates. It is non-invasive, radiation-free, repeatable, and can be performed without sedation or transport, making it particularly suitable for critically ill infants in neonatal intensive care units. [2]

Transcranial ultrasound has become an indispensable screening and diagnostic tool for detecting germinal matrix hemorrhage, intraventricular hemorrhage, ventricular abnormalities, white matter injury, and other intracranial pathologies. Serial examinations allow grading of hemorrhage, monitoring of disease progression, and early detection of complications such as post-hemorrhagic ventricular dilatation, facilitating timely intervention and improved neurological outcomes. [3,4] White matter injury may appear as increased periventricular echogenicity in mild cases and cystic changes in severe cases. Although subtle non-cystic lesions may be better characterized by advanced imaging modalities, ultrasound remains a practical and cost-effective tool for screening and longitudinal follow-up, especially in resource-limited settings. [4,5]

In addition to hemorrhagic, ischemic, and white matter injuries, transcranial ultrasound plays an important role in the evaluation of congenital brain anomalies and neonatal central nervous system infections. Ventricular abnormalities, cortical developmental malformations, posterior fossa anomalies, and sequelae of intrauterine infections may become evident during the neonatal period and can often be detected through careful neurosonographic assessment. Early identification of these conditions is essential for guiding further diagnostic investigations, multidisciplinary management, and long-term neurodevelopmental follow-up. [6]

Among neonatal brain injuries, germinal matrix and intraventricular hemorrhage (GMH-IVH) are closely linked to the immaturity of the developing cerebral vasculature. Transcranial ultrasound provides a unique opportunity to evaluate these lesions through assessment of tissue echogenicity and ventricular morphology. [7]

In addition to structural assessment, transcranial Doppler (TCD) ultrasonography provides real-time information on cerebral blood flow, vascular resistance, perfusion, and autoregulation. Doppler-derived parameters are valuable in conditions such as perinatal asphyxia, sepsis, patent ductus arteriosus, and hypotension, where disturbances in cerebral hemodynamics may contribute to brain injury. [8,9]

Overall, transcranial ultrasound plays a central role in the evaluation of brain insults in high-risk neonates by providing timely, reliable, and actionable bedside information. Its ability to detect, monitor, and characterize neonatal brain injury contributes significantly to improving neurological outcomes and remains particularly valuable in resource-constrained settings. [10,11]

The aim of this study was to evaluate transcranial ultrasound in evaluation of brain insults in high risk neonates.

2. Materials and Methods

The cross-sectional observational study was conducted in the Department of Radiodiagnosis at Index Medical College Hospital and Research Centre, Indore, Madhya Pradesh, India, for a period of 18 months after receiving ethical clearance from the Institutional Ethics Committee. Using a purposive sampling technique, 100 neonates fulfilling the inclusion and exclusion criteria were selected for the study. The study was conducted in accordance to the Declaration of Helsinki.

Inclusion Criteria

Both term (≥37 weeks gestation) and preterm (<37 weeks gestation) neonates admitted to the NICU for suspected or confirmed neurological compromise or for monitoring due to high-risk conditions, Asymptomatic neonates born from high-risk pregnancies (e.g., maternal pre-eclampsia, diabetes, antepartum haemorrhage, prolonged labour, meconium-stained liquor) who were suspected to be at risk for subtle neurological deficits were also included to evaluate the screening potential of TCUS, neonates whose parents or legal guardians provided written, informed consent

Exclusion Criteria

Neonates with suspected or confirmed intrauterine growth restriction (IUGR) were excluded, as IUGR itself can independently influence brain development and maturation, potentially confounding the study's focus on acute brain insults, with a known history of in-utero exposure to neurotoxic substances or medications, whose parents or guardians were unwilling to participate or refused consent.

Procedure

A detailed clinical history and relevant physical examination were performed for all neonates, followed by pretest counselling of parents or guardians. Cranial ultrasonography was conducted at the earliest clinically feasible time after birth or admission, predominantly at the bedside in the neonatal intensive care unit (NICU) to minimize handling of critically ill infants. Strict aseptic precautions, including hand hygiene and transducer disinfection, were maintained throughout the procedure.

Neonates were examined in the supine position with slight elevation of the head and shoulders. To prevent hypothermia, the examination room and ultrasound gel were prewarmed. Imaging was performed using Voluson S8 and LOGIQ P9 ultrasound systems equipped with high-frequency linear array transducers (3–8 MHz and 3–12 MHz, respectively). Scanning was primarily conducted through the anterior fontanelle, with supplementary views obtained through the posterior fontanelle when indicated.

A standardized imaging protocol was followed, including a minimum of five coronal sections, one midline sagittal section, and two parasagittal sections. These views enabled systematic evaluation of the cerebral parenchyma, basal ganglia, thalami, white matter, ventricular system, choroid plexus, corpus callosum, and posterior fossa structures. Image quality was optimized through careful transducer positioning and stabilization. All static images and cine loops were archived in the hospital Picture Archiving and Communication System (PACS) for subsequent review and analysis.

Data entry was carried out using a pre-designed proforma and entered into Microsoft excel for further analysis. Statistical analysis was conducted using the SPSS version 22.0 . The data was analyzed using descriptive statistics. All tests were taken to have a p-value of less than 0.05.

3. Results

Table 1: Gestational Age Category

Category	Frequency	Percentage (%)
Term	51	51.0
Preterm	38	38.0
Very Preterm	11	11.0

Term neonates formed 51 percent of the population of the study. However, nearly half (49%) were preterm or very preterm, which implies that there is a high burden of prematurity. Very preterm neonates contributed 11% which is clinically significant as it has a high risk of morbidity.

Table 2: Birth Weight (kg)

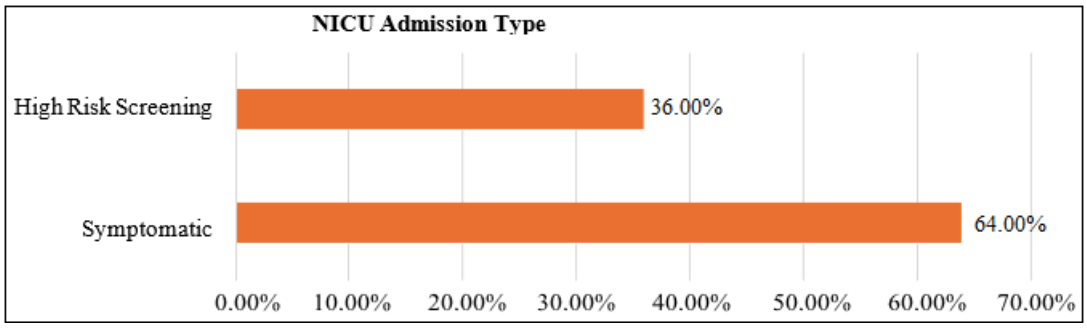
Statistic	Value
Mean	2.26
SD	0.70
Minimum	0.90
Maximum	3.40

The average weight of the births was 2.26 with a standard deviation of 0.70 kg which showed that there were more low birth weight babies. The lowest birth weight was 0.90 kg, which indicates very low cases of birth weight. The distribution is moderately variable amongst the neonates.

Table 3: NICU Admission Type

Category	Frequency	Percentage (%)
Symptomatic	64	64.0%
High Risk Screening	36	36.0%

Most of the neonates (64%), were hospitalized as a result of clinical symptoms, whereas 36% of them were admitted on high-risk screening. In spite of the fact that a higher rate of symptomatic admissions was observed, significant percentage of neonates were hospitalized in the context of surveillance because of the detected perinatal risk factors. This distribution is based on a balanced NICU population, comprising of clinically ill and high-risk yet stable neonates.

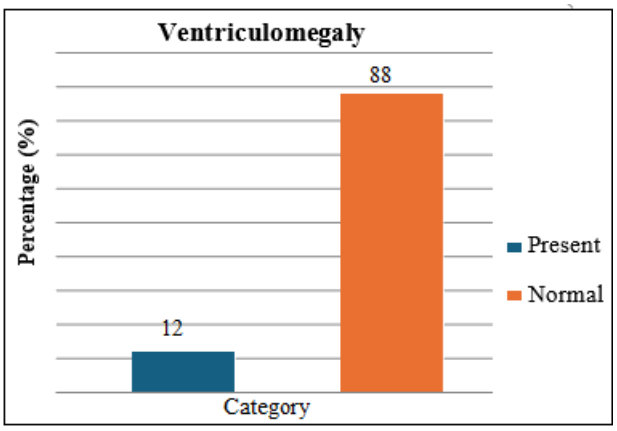


Graph 1: NICU Admission Type

Table 4: Ventriculomegaly (+/-)

Category	Frequency	Percentage (%)
Present	12	12%
Normal	88	88%

Ventriculomegaly was present in 12% of neonates. The majority (88%) had normal ventricular size. Although not highly prevalent, ventriculomegaly is clinically significant as it may indicate hydrocephalus or intraventricular pathology. Its presence in over one-tenth of neonates suggests a meaningful burden of ventricular abnormalities.

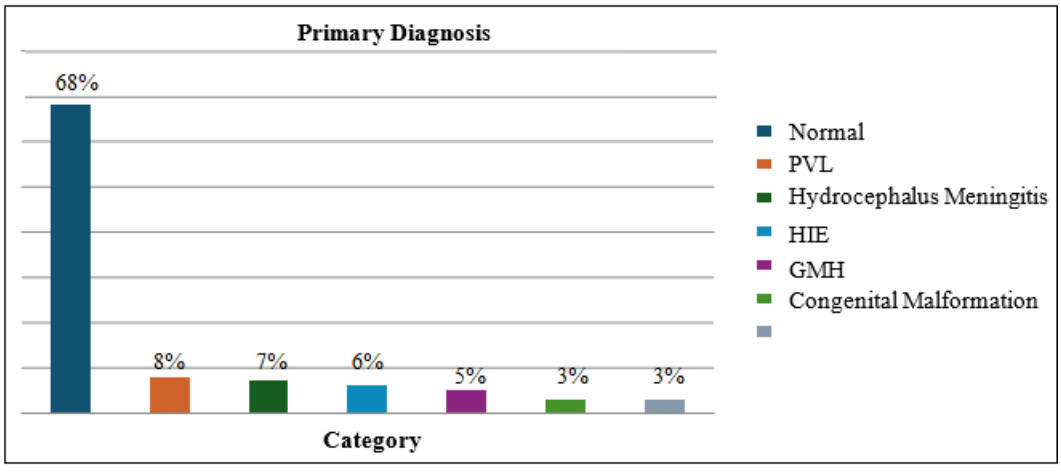


Graph 2: Ventriculomegaly

Table 5: Distribution of Primary Diagnosis

Diagnosis	Frequency	Percentage (%)
Normal	68	68%
Periventricular Leukomalacia (PVL)	8	8%
Hydrocephalus	7	7%
Meningitis	6	6%
Hypoxic Ischemic Encephalopathy (HIE)	5	5%
Germinal Matrix Hemorrhage (GMH)	3	3%
Congenital Malformation	3	3%

The majority of neonates (68%) had normal imaging findings, indicating no structural abnormality detected on USG. Among abnormal diagnoses, Periventricular Leukomalacia (8%) and Hydrocephalus (7%) were the most common conditions observed. Infective causes such as Meningitis accounted for 6% of cases, while hypoxic and hemorrhagic conditions (HIE and GMH) together comprised 8% of cases. Congenital malformations were relatively rare (3%), indicating that most abnormalities were acquired rather than structural congenital defects.



Graph 3: Diagnosis

Table 6: GA Category × Ventriculomegaly

GA Category	Ventriculomegaly Present	Normal	Chi-square	p-value
Term (n=51)	2	49	8.42	0.014*
Preterm (n=38)	7	31		
Very Preterm (n=11)	3	8		

There was a statistically significant association between gestational age and ventriculomegaly (p= 0.014). Ventriculomegaly was more frequently observed in preterm and very preterm neonates compared to term babies. This suggests that prematurity increases the risk of ventricular abnormalities. The finding supports the importance of early

transcranial ultrasound screening in preterm neonates.

Table 7: GA Category × Periventricular Echogenicity

GA Category	Present	Absent	Chi-square	p-value
Term	1	50	16.75	0.0002*
Preterm	8	30		
Very Preterm	5	6		

A highly significant association was found between gestational age and periventricular echogenicity ($p < 0.001$). The prevalence was markedly higher in very preterm neonates. This supports the known vulnerability of immature white matter in preterm infants. Early ultrasound screening plays a critical role in detecting such lesions.

Table 8: Periventricular Echogenicity × Final Diagnosis

PV Echogenicity	PVL Diagnosis	Other Diagnoses	Chi-square	p-value
Present (n=14)	7	7	41.62	<0.001
Absent (n=86)	1	85		

A highly significant association was observed between periventricular echogenicity and final diagnosis of PVL ($p < 0.001$). Nearly half of neonates with PV echogenicity were diagnosed with PVL. This demonstrates strong diagnostic correlation between ultrasound findings and clinical diagnosis. It supports the validity of transcranial ultrasound as an early predictor of white matter injury.

Table 9: Ventriculomegaly × Hydrocephalus

Ventriculomegaly	Hydrocephalus	Other Diagnoses	Chi-square	p-value
Present (n=12)	6	6	36.48	<0.001*
Normal (n=88)	1	87		

There was a statistically significant association between ventriculomegaly and hydrocephalus ($p < 0.001$). Half of the neonates with ventricular enlargement were diagnosed with hydrocephalus. This confirms the strong diagnostic value of ventricular measurement on ultrasound. Early detection facilitates timely neurosurgical decision-making.

Table 10: Ventriculitis × Meningitis

Ventriculitis	Meningitis	Other Diagnoses	Chi-square	p-value
Present (n= 7)	5	2	52.31	<0.001*
Normal (n= 93)	1	92		

A very strong association was identified between ventriculitis on ultrasound and meningitis diagnosis ($p < 0.001$). The majority of neonates with echogenic sulci were clinically diagnosed with meningitis. This demonstrates excellent correlation between imaging and infection-related brain pathology. Transcranial ultrasound is therefore highly useful for early detection of infective insults.

Table 11: Caudothalamic Echogenicity × Germinal Matrix Hemorrhage

CT Echogenicity	GMH	Other Diagnoses	Chi-square	p-value
Present (n= 2)	2	0	64.87	<0.001
Normal (n= 98)	1	97		

All neonates with caudothalamic echogenicity were diagnosed with germinal matrix hemorrhage. The association was statistically highly significant ($p < 0.001$). This confirms the diagnostic specificity of this ultrasound finding for hemorrhagic pathology. It strongly supports the role of transcranial ultrasound in early hemorrhage detection.

Table 12: Correlation Summary (Cramer's V)

Variable 1	Variable 2	Cramer's V	p-value	Interpretation
GA Category	PV Echogenicity	0.41	<0.001*	Moderate positive association
GA Category	Ventriculomegaly	0.29	0.014*	Mild–moderate association
Birth Weight Category	PV Echogenicity	0.30	0.002*	Moderate association
Seizures	PV Echogenicity	0.41	<0.001*	Moderate–Strong association
Lethargy	Ventriculomegaly	0.22	0.030*	Mild association
Apnea	Ventriculitis	0.25	0.013*	Mild–moderate association
Hypertonia	GMH	0.20	0.046*	Mild association
Ventriculomegaly	Hydrocephalus	0.60	<0.001*	Strong association
PV Echogenicity	PVL	0.64	<0.001*	Strong association
Ventriculitis	Meningitis	0.71	<0.001*	Very strong association
CT Echogenicity	GMH	0.81	<0.001*	Very strong association

The strongest correlations were observed between specific ultrasound findings and their corresponding diagnoses, particularly caudothalamic echogenicity with GMH and ventriculitis with meningitis. Gestational age showed moderate association with periventricular echogenicity, confirming the role of prematurity in white matter injury. Clinical symptoms demonstrated mild to moderate associations with imaging findings, supporting the use of transcranial ultrasound in early symptomatic neonates. Overall, the correlation analysis validates ultrasound as a reliable diagnostic and predictive tool.

Table 13: Logistic Regression – Predictors of Abnormal USG

Predictor	Adjusted Odds Ratio (AOR)	95% CI	p-value	Interpretation
Preterm (vs Term)	3.4	1.4–8.2	0.006*	Significant risk factor
Very Preterm (vs Term)	5.8	1.8–18.4	0.003*	Strong independent predictor
Low Birth Weight	2.9	1.2–6.7	0.015*	Significant predictor
Seizures	4.6	1.9 – 11.2	0.001*	Strong independent predictor
Apnea	2.4	1.0–5.9	0.041*	Significant association
Hypertonia	2.1	0.8–5.3	0.112	Not independently significant

Very preterm neonates had nearly six times higher odds of abnormal ultrasound findings compared to term neonates. Low birth weight independently increased the risk of

abnormal neurosonography by almost threefold. Clinical symptoms such as seizures and apnea were significant independent predictors of abnormal ultrasound findings. Hypertonia, although associated on univariate analysis, did not remain independently significant. This model confirms that prematurity and clinical manifestations are strong predictors of early brain insult detectable on transcranial ultrasound.

4. Discussion

Prematurity constituted a major component of the study population, with 49% of neonates being preterm or very preterm. This finding is clinically important because immature cerebral vasculature and white matter are highly susceptible to hypoxic, hemorrhagic, and ischemic insults. Similar observations have been reported by Fumagalli et al. [12], who identified lower gestational age as a significant predictor of adverse cranial ultrasound outcomes. Diwakar et al. [13] also demonstrated a higher frequency of cranial ultrasound abnormalities among preterm infants. The substantial proportion of preterm neonates in the present study provided an appropriate high-risk population for evaluating the utility of transcranial ultrasound.

The mean birth weight was 2.26 ± 0.70 kg, reflecting a predominance of low birth weight (LBW) neonates. Low birth weight is a recognized risk factor for cerebral injury because of its association with prematurity, impaired cerebral autoregulation, and increased vulnerability to white matter damage. Diwakar et al. [13] reported a strong association between low birth weight and neurosonographic abnormalities in preterm infants. The present findings further support the importance of early ultrasound screening in LBW neonates.

Most neonates were admitted because of clinical symptoms (64%), while 36% underwent screening based on high-risk perinatal factors. Despite the inclusion of asymptomatic high-risk neonates, abnormal ultrasound findings were identified in 32% of the cohort, highlighting the value of routine neurosonographic screening. Fumagalli et al. [12] similarly demonstrated that cranial ultrasound can detect clinically relevant abnormalities even in screened populations with initially subtle manifestations.

Ventriculomegaly was detected in 12% of neonates, indicating a substantial burden of ventricular abnormalities. This prevalence is comparable to findings reported by Diwakar et al. [13], who observed hydrocephalus in 12% of preterm infants undergoing serial cranial ultrasound. Ventricular enlargement is an important marker of hydrocephalus, post-hemorrhagic ventricular dilatation, and other intracranial pathologies, emphasizing the diagnostic value of transcranial ultrasound.

Although 68% of neonates demonstrated normal ultrasound findings, significant abnormalities were identified in 32% of cases. Periventricular leukomalacia (8%) and hydrocephalus (7%) were the most frequent diagnoses, followed by meningitis (6%), hypoxic ischemic encephalopathy (5%), germinal matrix hemorrhage (3%), and congenital malformations (3%). These findings indicate that acquired brain injuries were more common than congenital abnormalities and underscore the role of ultrasound in detecting a broad spectrum of neonatal brain insults.

A significant association was observed between gestational age and ventriculomegaly ($p=0.014$), with higher frequencies among preterm and very preterm neonates. This finding is consistent with previous reports demonstrating increased susceptibility of premature infants to ventricular abnormalities and post-hemorrhagic complications [13]. The results support targeted ultrasound screening in preterm populations.

Periventricular echogenicity showed a highly significant association with gestational age ($p=0.0002$), being most prevalent among very preterm neonates. This observation aligns with the findings of Fumagalli et al. [66], who reported increased rates of periventricular hyperechogenicity in preterm infants. The results highlight the vulnerability of immature white matter and reinforce the importance of early neurosonographic surveillance in premature neonates.

Periventricular echogenicity demonstrated a strong association with the final diagnosis of periventricular leukomalacia (PVL) ($p<0.001$). Nearly half of neonates with this ultrasound finding were subsequently diagnosed with PVL, confirming its clinical significance as an early marker of white matter injury. This finding supports the diagnostic accuracy of transcranial ultrasound for identifying preterm-related white matter damage.

A highly significant association was observed between ventriculomegaly and hydrocephalus ($p<0.001$). Half of the neonates with ventricular enlargement were ultimately diagnosed with hydrocephalus, confirming the diagnostic utility of ventricular measurements during cranial ultrasound. Early recognition of ventricular dilatation facilitates timely monitoring and neurosurgical referral when required.

Ventriculitis demonstrated a very strong association with meningitis ($p<0.001$). Most neonates exhibiting echogenic sulci or ventricular debris were clinically diagnosed with meningitis, indicating excellent concordance between sonographic findings and infectious pathology. Similar observations have been emphasized by Aro-Dominguez et al. [14] and Vinci et al. [15], who highlighted the role of cranial ultrasound in the evaluation of neonatal central nervous system infections.

All neonates with caudothalamic echogenicity were diagnosed with germinal matrix hemorrhage, resulting in a highly significant association ($p<0.001$). This finding confirms the well-established specificity of caudothalamic echogenicity as a sonographic marker of germinal matrix hemorrhage and demonstrates the effectiveness of transcranial ultrasound in detecting early hemorrhagic lesions in high-risk neonates.

Correlation analysis demonstrated the strongest associations between specific ultrasound findings and their corresponding diagnoses. Caudothalamic echogenicity showed a very strong correlation with germinal matrix hemorrhage (Cramer's $V=0.81$), while ventriculitis demonstrated a very strong

correlation with meningitis (V=0.71). Periventricular echogenicity was strongly associated with PVL (V=0.64), and ventriculomegaly was strongly associated with hydrocephalus (V=0.60). Moderate correlations were observed between gestational age and periventricular echogenicity (V=0.41), as well as between seizures and periventricular echogenicity (V=0.41). These findings validate the diagnostic reliability of transcranial ultrasound in identifying neonatal brain injury.

Multivariable logistic regression identified prematurity, low birth weight, seizures, and apnea as independent predictors of abnormal ultrasound findings. Preterm neonates had 3.4-fold higher odds of abnormal neurosonography, while very preterm neonates had 5.8-fold higher odds compared with term neonates. Low birth weight increased the risk nearly threefold, and seizures emerged as the strongest clinical predictor (AOR 4.6). Apnea was also independently associated with abnormal ultrasound findings. These findings are consistent with the observations of Fumagalli et al. [66], who demonstrated that gestational age and neonatal comorbidities are major determinants of adverse cranial ultrasound outcomes. The results support routine transcranial ultrasound screening in very preterm, low birth weight, seizure-presenting, and apneic neonates to facilitate early diagnosis and intervention.

The present study possesses several strengths, including the evaluation of a well-characterized cohort of 100 high-risk neonates encompassing term, preterm, and very preterm infants, enabling assessment of prematurity-related brain injury. Comprehensive documentation of clinical manifestations and neurosonographic findings allowed meaningful clinicoradiological correlations, while the application of chi-square analysis, Cramer's V, and multivariable logistic regression identified independent predictors of abnormal ultrasound findings, including very preterm birth, low birth weight, seizures, and apnea. The strong concordance between ultrasound findings and final diagnoses, particularly between periventricular echogenicity and PVL, ventriculomegaly and hydrocephalus, ventriculitis and meningitis, and caudothalamic echogenicity and GMH, further supports the diagnostic reliability of transcranial ultrasound. However, the study is limited by its single-center observational design, relatively modest sample size, and absence of long-term neurodevelopmental follow-up, which may restrict generalizability and assessment of prognostic significance. In addition, rare pathologies were represented by small numbers, interobserver variability was not evaluated, Doppler parameters were not included, and the lack of a low-risk control group limits comparative analysis. Furthermore, ultrasound has inherent limitations in detecting subtle cortical lesions, posterior fossa abnormalities, and diffuse hypoxic injuries when compared with MRI. Nevertheless, the findings strongly support transcranial ultrasound as a practical and effective first-line neuroimaging modality for high-risk neonates.

5. Conclusion

The study findings demonstrates that transcranial ultrasound is an effective first-line neuroimaging technique that can be used in the early detection of brain insults in high-risk neonates. It is a fast, bedside, radiation-free imaging modality that can be used to identify hemorrhagic ischemic, ventricular and infective pathologies. Transcranial ultrasound is a vital imaging technique that can be used both as a screening and diagnostic tool in resource poor settings where screening and diagnostic of MRI is not easily accessible.

Transcranial ultrasound plays a critical role in imaging of brain offenses at an early stage in high-risk neonates. The risk factors of preterm births, low birth weights, and seizure as well as apnea are significant predisposing factors likely to lead to abnormal neurosonographic results.

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