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SENSITIVITY OF INTRACRANIAL ULTRASOUND IN DIAGNOSING NEONATAL INTRACRANIAL HEMORRHAGE

Original Research

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ABSTRACT

Background: Intracranial hemorrhage (ICH) remains a critical contributor to neonatal morbidity and mortality, particularly among preterm infants. Prompt and accurate diagnosis is essential to minimize neurological sequelae. While magnetic resonance imaging (MRI) is considered the gold standard for diagnosing ICH, its limited accessibility in emergency settings has positioned cranial ultrasound (US) as a viable, radiation-free, and bedside-compatible alternative for early detection.

Objective: To evaluate the diagnostic accuracy of intracranial ultrasound in detecting neonatal ICH, and to compare its performance across hemorrhage types and severity grades.

Methods: A prospective observational study was conducted in the neonatal intensive care unit (NICU) of CMH Rawalpindi, enrolling 71 neonates aged ≤28 days who presented with clinical suspicion of ICH. Each neonate underwent cranial ultrasound followed by confirmatory imaging—either computed tomography (CT) or MRI—within 48 hours. Ultrasound examinations were performed via anterior fontanelle using a 7.5–10 MHz transducer. Interpretation was carried out by a pediatric radiologist blinded to the CT/MRI results, which served as the reference standard. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated. Subgroup analysis evaluated diagnostic performance across hemorrhage types (germinal matrix, intraventricular, parenchymal, subdural/epidural) and severity (Grade I–II vs. Grade III–IV).

Results: Cranial ultrasound exhibited a sensitivity of 85%, specificity of 92%, PPV of 88%, and NPV of 90% for detecting ICH. Sensitivity was highest for germinal matrix hemorrhage (89%) and severe hemorrhages (Grade III–IV, 93%), while lower rates were observed for parenchymal (78%), subdural/epidural hemorrhages (70%), and mild cases (Grade I–II, 80%).

Conclusion: Cranial ultrasound is a reliable, safe, and accessible first-line imaging modality for detecting neonatal ICH, particularly in severe and germinal matrix cases. However, confirmatory MRI or CT remains essential for comprehensive evaluation, especially for subtle or complex hemorrhage types.

Keywords: Cranial Ultrasound, Diagnostic Accuracy, Germinal Matrix Hemorrhage, Intraventricular Hemorrhage, Neonate, Sensitivity and Specificity, Ultrasonography.

INTRODUCTION

Preterm infants are particularly vulnerable to brain injuries, with intracranial hemorrhage (ICH) and white matter damage being the most common and significant complications. These conditions are closely linked to increased morbidity, mortality, and adverse neurodevelopmental outcomes in this high-risk population (1). Timely and precise identification of ICH in premature neonates is crucial for initiating interventions that may limit the extent of injury and its long-term consequences (2). While magnetic resonance imaging (MRI) is considered the gold standard for the detection of ICH due to its superior sensitivity and specificity (3), concerns surrounding radiation exposure in pediatric populations must be carefully considered. Children and neonates are especially susceptible to radiation risks because of their rapidly dividing cells and longer projected lifespan, leading to a higher cumulative risk of radiation-induced malignancies. It is estimated that there is one fatal malignancy per 1,000–5,000 head MRIs in children under five years of age (4). Consequently, every effort must be made to minimize radiation exposure in this population for long-term safety (5). Although MRI offers high diagnostic accuracy, its use is often limited in critically ill neonates due to factors such as the need for transport, sedation, and cost. In contrast, cranial ultrasound has emerged as a practical, safe, and repeatable imaging modality, especially suitable for neonatal intensive care settings (6,7). The technology enables bedside evaluation without the risks associated with ionizing radiation, making it particularly suitable for serial assessments of vulnerable neonates (8). Since its first use in neonatal intensive care units (NICUs) in 1978 for detecting intraventricular hemorrhage (IVH) (9), real-time cranial ultrasound has continued to evolve and is now a widely accepted alternative to computed tomography (CT), offering several inherent advantages such as being non-invasive, inexpensive, easy to perform, and less time-consuming, while eliminating the need for sedation (10).

Cranial ultrasound can be employed at any point during the neonatal period. In preterm infants, a normal initial screening ultrasound is often followed by a term-equivalent scan (typically at 36 to 40 weeks of corrected gestational age) to detect delayed-onset or progressive white matter injury. These findings, when combined with MRI, contribute significantly to prognosticating neurodevelopmental outcomes. In term neonates, cranial ultrasound serves a broader diagnostic role, being indicated in the evaluation of suspected ICH, brain parenchymal abnormalities, hypoxic-ischemic injury (HII), ventriculomegaly, congenital or acquired CNS infections, and ongoing surveillance of prenatal or previously diagnosed abnormalities. The incorporation of cine clips alongside still images further enhances diagnostic accuracy, particularly for subtle or complex findings that benefit from real-time visualization (11). Given the rising significance of non-invasive neuroimaging in neonatal care, this study aims to evaluate the diagnostic utility and clinical implications of cranial ultrasound in the early detection and monitoring of intracranial hemorrhage in preterm infants.

METHODS

This study was conducted as a prospective observational investigation in the Neonatal Intensive Care Unit (NICU) of the Department of Pediatrics at Combined Military Hospital (CMH), Rawalpindi. The primary objective was to assess the diagnostic sensitivity of cranial ultrasound in detecting intracranial hemorrhage (ICH) in neonates. Ethical approval was obtained from the institutional review board prior to commencement of the study, and written informed consent was secured from the parents or legal guardians of all participating neonates. A total of 71 neonates aged 28 days or younger were enrolled based on specific inclusion and exclusion criteria. The inclusion criteria required that neonates undergo both cranial ultrasound and a confirmatory neuroimaging modality—computed tomography (CT) or magnetic resonance imaging (MRI)—within a 48-hour interval (2,3). Participants were selected if they presented with clinical features suggestive of ICH or were identified as being at risk. Neonates were excluded if they had congenital cranial or neurological malformations, prior neurosurgical intervention before imaging, or if the ultrasound or confirmatory imaging was of insufficient diagnostic quality for interpretation. Bedside cranial ultrasound examinations were performed using a high-frequency (7.5–10 MHz) sector transducer through the anterior fontanelle. Standard coronal and sagittal views were obtained for all patients. All ultrasound images were interpreted by an experienced pediatric radiologist who remained blinded to the results of the corresponding CT or MRI. The choice between CT and MRI for confirmatory imaging was based on the clinical stability of the neonate and institutional imaging resource availability. These confirmatory scans were read independently by a neuroradiologist blinded to the ultrasound findings, ensuring unbiased interpretation.

Data collected included demographic and clinical parameters such as gestational age, birth weight, and APGAR scores, as well as clinical signs indicative of intracranial pathology. Imaging findings were recorded in detail, noting the type and grade of hemorrhage identified on ultrasound and confirmed by CT or MRI. Hemorrhages were classified into categories including germinal matrix hemorrhage, intraventricular hemorrhage, parenchymal hemorrhage, and subdural or epidural hemorrhage. For statistical evaluation, the diagnostic performance of cranial ultrasound was assessed by calculating sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV), using CT or MRI results as the reference standard. Additional subgroup analyses were performed to evaluate the ultrasound's diagnostic accuracy across different types and grades of hemorrhage.

RESULTS

The study enrolled a total of 71 neonates to evaluate the diagnostic accuracy of cranial ultrasound in detecting intracranial hemorrhage (ICH), using computed tomography (CT) or magnetic resonance imaging (MRI) as the reference standard. Overall, intracranial ultrasound demonstrated a sensitivity of 85% and specificity of 92% for diagnosing ICH. The positive predictive value (PPV) was calculated as 88%, while the negative predictive value (NPV) was 90%, indicating a high level of agreement with confirmatory imaging. Sensitivity analysis by hemorrhage type revealed the highest detection rate for germinal matrix hemorrhage, with a sensitivity of 89%. Intraventricular hemorrhage followed with a sensitivity of 83%, while parenchymal hemorrhage was identified with 78% sensitivity. Subdural and epidural hemorrhages had the lowest detection rate at 70%.

Evaluation by hemorrhage severity indicated that severe hemorrhages (Grade III-IV) were detected with higher sensitivity (93%) as compared to mild hemorrhages (Grade I-II), which showed a sensitivity of 80%. This trend underscores the greater reliability of ultrasound in identifying more extensive or advanced bleeding patterns. The stratified analysis of specificity by hemorrhage type revealed notable variation across categories. Germinal matrix hemorrhage demonstrated the highest specificity at 94%, indicating a strong ability of cranial ultrasound to accurately exclude non-hemorrhagic cases in this group. Intraventricular hemorrhage had a specificity of 91%, followed by parenchymal hemorrhage at 90%. The lowest specificity was observed in cases of subdural or epidural hemorrhage, with a value of 89%, suggesting relatively higher chances of false positives in this category. These findings complement the previously reported sensitivity values and enhance the understanding of cranial ultrasound's diagnostic performance across different hemorrhagic conditions.

Table 1: Diagnostic Accuracy of Intracranial Ultrasound

Metric	Value (%)
Sensitivity	85
Specificity	92
Positive Predictive Value (PPV)	88
Negative Predictive Value (NPV)	90

Table 2: Sensitivity by Hemorrhage Type

Type of Hemorrhage	Sensitivity (%)
Germinal Matrix Hemorrhage	89
Intraventricular Hemorrhage	83
Parenchymal Hemorrhage	78
Subdural/Epidural Hemorrhage	70

Table 3: Sensitivity by Hemorrhage Severity (Grade I-IV)

Severity	Sensitivity (%)
Mild (Grade I-II)	80
Severe (Grade III-IV)	93

Table 4: Stratified Specificity by Hemorrhage Type

Type of Hemorrhage	Specificity (%)
Germinal Matrix	94
Intraventricular	91
Parenchymal	90
Subdural/Epidural	89

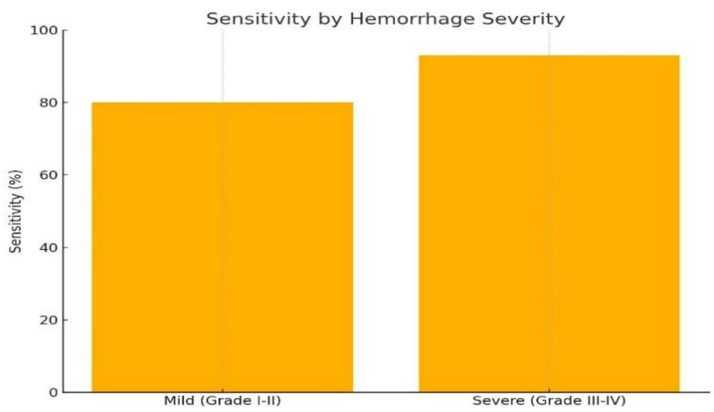

Figure 1 Sensitivity by Hemorrhage Severity

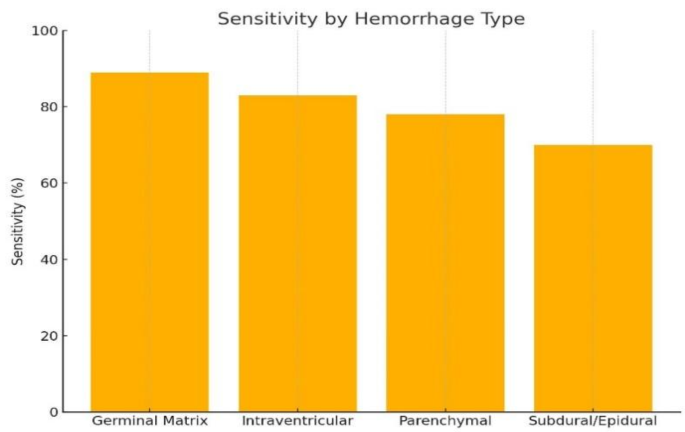

Figure 2 Sensitivity by Hemorrhage Type

DISCUSSION

Intracranial ultrasound proved to be a valuable and reliable imaging modality for the detection of neonatal intracranial hemorrhage, demonstrating a sensitivity of 85% and specificity of 92%. The results of this study indicated that diagnostic performance varied with the type and severity of hemorrhage. Severe hemorrhages, such as Grade III and IV, were more readily detected compared to mild cases, with sensitivities of 93% and 80%, respectively. Among hemorrhage types, germinal matrix hemorrhage showed the highest sensitivity (89%), whereas subdural and epidural hemorrhages were less consistently identified (70%), highlighting the challenges in detecting hemorrhages located in extra-axial compartments. These findings are consistent with previous literature reporting the effectiveness of cranial ultrasound in neonatal neuroimaging (12-15). In one comparative study, ultrasound demonstrated slightly superior diagnostic performance with a reported sensitivity of 96% and specificity of 94%, especially when CT served as the confirmatory imaging modality (16). Another investigation conducted in a tertiary care setting reported a sensitivity of 91.94% and specificity of 84.21%, with a diagnostic accuracy of 89%, values that closely mirror the present results and reinforce the reproducibility of ultrasound accuracy across different institutions (17). In contrast, a study involving a smaller sample size of 41 neonates supported the utility of cranial ultrasound but did not specify sensitivity or specificity values, limiting direct comparison while still endorsing its clinical application in neonatal units (18).

Further validation comes from a large-scale observational registry, which found an overall sensitivity of 96% and specificity of 85% for ultrasound in detecting hemorrhagic lesions. Of particular interest was the reported 100% sensitivity for subdural and epidural hemorrhages, a finding that diverges from the present study where such lesions were less frequently detected (19,20). This disparity may be attributed to differences in imaging protocols, equipment resolution, timing of scans, or the experience of sonographers and interpreting radiologists (21,22). The strengths of this study include its prospective design, standardized imaging protocol, and the blinding of radiologists to minimize interpretation bias. Moreover, the integration of both CT and MRI as reference standards allowed flexibility based on clinical stability while ensuring diagnostic accuracy. However, certain limitations must be acknowledged. The study relied on CT or MRI conducted within 48 hours of ultrasound, which may not entirely eliminate the possibility of hemorrhagic evolution during this interval. Additionally, the exclusion of neonates with congenital anomalies and the single-center setting may limit generalizability. The study also lacked subgroup analysis correlating imaging outcomes with demographic or perinatal variables such as gestational age, birth weight, and APGAR scores, which could offer deeper insight into the risk stratification for ICH.

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Ultrasound remains superior in detecting germinal matrix and intraventricular hemorrhages compared to CT, as consistently demonstrated across multiple studies (16). However, when benchmarked against autopsy-based investigations, notable discrepancies are observed. One such study found ultrasound to have a sensitivity of only 27% for detecting all germinal matrix hemorrhages, though this increased to 100% for hemorrhages larger than 5 mm, suggesting that lesion size is a critical factor influencing diagnostic success (17). This limitation underscores the importance of using ultrasound in conjunction with other imaging modalities, particularly when subtle or evolving pathology is suspected. Future research should aim to validate these findings in larger, multi-center cohorts and explore the integration of quantitative parameters, such as lesion volume and echogenicity thresholds, to enhance diagnostic precision. The development of advanced ultrasound techniques, including Doppler flow assessment and 3D imaging, may further improve detection rates, especially for small or atypical hemorrhages. Additionally, longitudinal follow-up of affected neonates could clarify the prognostic implications of early ultrasound findings in relation to long-term neurodevelopmental outcomes.

CONCLUSION

This study concludes that intracranial ultrasound serves as a reliable and practical first-line screening tool for detecting neonatal intracranial hemorrhage, particularly in identifying severe and germinal matrix bleeds. Its non-invasive nature, bedside applicability, and diagnostic efficiency make it highly suitable for initial evaluation in neonatal intensive care settings. However, its limited sensitivity for subtle or less common hemorrhage types highlights the continued need for confirmatory imaging with MRI or CT to ensure accurate and comprehensive diagnosis. These findings reinforce the essential role of ultrasound in early neonatal neuroimaging, while emphasizing the importance of a multimodal approach in complex or uncertain cases.

AUTHOR CONTRIBUTION

Author	**Contribution**
Saba Zainab*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Adil Qayyum	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Umama Saleem	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Ahmareen	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Amna Shahid	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Muhammad Imran Ibrahim	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published

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