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DIAGNOSTIC ACCURACY OF ULTRASONOGRAPHY IN DIAGNOSING HYDROCEPHALUS IN INFANTS USING COMPUTED TOMOGRAPHY AS THE GOLD STANDARD

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Abstract

Background: *Hydrocephalus in infants necessitates accurate diagnosis to prevent neurodevelopmental complications. While computed tomography (CT) remains the gold standard, its ionizing radiation poses significant pediatric risks. Ultrasonography (USG) offers a radiation-free alternative, but its diagnostic performance requires rigorous validation.*

Objective: *To determine the diagnostic accuracy of cranial ultrasonography for infant hydrocephalus using CT as the reference standard.*

Methods: *In this cross-sectional study, 164 infants (aged 0–12 months) with clinical suspicion of hydrocephalus underwent cranial USG followed by CT at a tertiary care hospital. Diagnostic accuracy was calculated via 2×2 contingency tables, with stratified analyses for age, gender, and clinical risk factors.*

Results: *CT confirmed hydrocephalus in 48.8% (80/164) of infants. USG demonstrated sensitivity of 88.8% (95% CI: 80.1–94.0), specificity of 52.4% (95% CI: 41.6–62.9), positive predictive value of 64.0%, negative predictive value of 83.0%, and overall accuracy of 70.1%. Infants aged <6 months showed higher sensitivity (91.7% vs. 85.7%) but lower specificity (41.7% vs. 65.0%) compared to older infants. Prematurity significantly reduced specificity (38.1% vs. 68.8%, p<0.001).*

Conclusion: *Ultrasonography exhibits excellent sensitivity for hydrocephalus screening but suffers from low specificity, particularly in preterm and young infants. CT remains essential for confirmation of positive USG results to avoid unnecessary interventions*

INTRODUCTION

Hydrocephalus represents a critical neurological condition characterized by disturbed cerebrospinal fluid dynamics, leading to pathological ventricular dilation. This disorder affects approximately 4.65 per 10,000 live births globally (Kahle et al., 2016), with post-hemorrhagic hydrocephalus occurring in 46.3% of infants with severe intraventricular hemorrhage (Gonţ et al., 2025; Kim et al., 2024). Infants typically present with macrocephaly, bulging fontanelles, or the "sunsetting" eye sign, while untreated hydrocephalus may cause irreversible brain damage, cognitive impairment, and developmental delays (Rekate & Blitz, 2016).

Computed tomography remains the established gold standard for hydrocephalus diagnosis due to its exceptional spatial resolution and diagnostic accuracy exceeding 90% (Rekate & Blitz, 2016). However, significant concerns persist regarding

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ionizing radiation exposure in pediatric populations. Children exhibit heightened radiosensitivity, with cumulative CT scans increasing lifetime cancer risks by up to 1 in 1,000, which is 0.07 higher than adult populations (Biegała et al., 2025; Gaillard et al., 2024). However, not all pediatric hydrocephalus patients face elevated radiation risks, with certain individuals being more susceptible based on cumulative exposure patterns (Romanowicz et al., 2022). This limitation is particularly acute in resource-constrained settings like Pakistan, where advanced imaging access remains limited.

Cranial ultrasonography offers a compelling alternative as a non-invasive, radiation-free modality. Its portability, low cost, and real-time imaging capabilities make it especially valuable for neonatal intensive care and regions with limited healthcare infrastructure (Ikram et al., 2020). Recent diagnostic accuracy studies demonstrate cranial ultrasonography's high sensitivity (100%) and specificity (90.6%) for detecting intracranial pathologies in neonates, with diagnostic accuracy of 94.2% when compared to magnetic resonance imaging as the gold standard (Patel et al., 2023; Sheikh & Shabbir, 2024). Contemporary evaluations show trans fontanelle sonography achieving a sensitivity of 66.7% and specificity of 88.9% for hydrocephalus detection using computed tomography as reference (Kaleemullah et al., 2025). The existing literature reveals a critical knowledge gap regarding ultrasonography's performance across diverse infant subgroups and clinical contexts.

This study aims to comprehensively evaluate the diagnostic accuracy of cranial ultrasonography for hydrocephalus in infants under 12 months, using computed tomography as the reference standard. Secondary objectives include stratifying accuracy by age, gender, and clinical risk factors to identify potential diagnostic modifiers. We hypothesize that ultrasonography demonstrates clinically acceptable sensitivity (>85%) and moderate specificity (>60%), supporting its utility as a frontline screening tool in pediatric neuroimaging.

Methods

Study Design and Setting

This cross-sectional diagnostic accuracy study was conducted at the Department of Radiology, Combined Military Hospital Abbottabad, Pakistan, over six months, receiving formal approval from the Institutional Review Board of Combined Military Hospital Abbottabad under reference IRB No. CMH-ABT-ETH-178—Radio-24. Written informed consent was obtained from the legal guardians of all enrolled infants after a comprehensive explanation of study procedures, risks, and benefits. Confidentiality was maintained through anonymized data coding and secure storage protocols. The study adhered to STARD guidelines for diagnostic test validation to ensure methodological rigor in assessing ultrasonography against the reference standard of computed tomography.

Participant Selection

A consecutive non-probability sampling technique enrolled 164 infants aged 0 to 12 months presenting with clinical features suggestive of hydrocephalus. Inclusion criteria comprised infants exhibiting one or more of the following signs: macrocephaly defined as head circumference exceeding the 97th percentile for age, bulging anterior fontanelle, diastasis of cranial sutures, prominent scalp veins, sunset eye sign, unexplained irritability, or recurrent vomiting. Exclusion criteria excluded infants with previous neurosurgical interventions, documented traumatic brain injury, or concurrent neurological disorders such as encephaloceles or intracranial tumors that might confound ventricular assessment.

Sample Size Determination

Sample size calculation was performed using WHO Sample Size Software version 2.0, yielding a minimum requirement of 164 participants. This calculation incorporated an anticipated sensitivity of 88.9% and specificity of 58.1% derived from prior literature on infant hydrocephalus diagnosis, alongside a reported hydrocephalus prevalence of 0.12% in the target population. The calculation preserved a 95% confidence level with 15% absolute precision to ensure statistical robustness.

Imaging Protocol and Interpretation

Ultrasonography examinations were conducted by consultant radiologists possessing a minimum of two years' specialized experience in neonatal neuroimaging. Examinations utilized an Esaote AU3

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ultrasound system equipped with a 5–7 MHz linear transducer. Hydrocephalus diagnosis via ultrasonography required a mean transverse diameter measurement exceeding 10 mm at the atrial level of the lateral ventricles. Computed tomography served as the reference standard and was performed using a Siemens Somatom 64-slice scanner. Radiologists interpreting CT images remained blinded to ultrasonography results, with hydrocephalus confirmation requiring fulfillment of either of two criteria: a bicaudate index exceeding the 95th percentile for age, or an axial width of the temporal horn measuring 5 mm or greater.

Data Collection Procedures

Standardized data collection proformas captured comprehensive variables including infant age in months, gender, weight in kilograms, and height in centimeters. Perinatal history documentation encompassed prematurity status, birth asphyxia occurrence, traumatic delivery events, and perinatal infections. Maternal factors recorded included age, comorbidities such as diabetes or hypertension, and family history of congenital hydrocephalus. Imaging outcomes were dichotomously classified as positive or negative for hydrocephalus based on predefined criteria for both modalities.

Statistical Analysis

Data analysis was conducted using IBM SPSS Statistics version 27.0. Descriptive statistics summarized continuous variables as means with standard deviations, after confirming normality via the Shapiro-Wilk test, while categorical variables were reported as frequencies and percentages. Diagnostic accuracy metrics, including sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy, were derived from 2×2 contingency tables comparing ultrasonography results against the computed tomography gold standard. Stratified analyses examined diagnostic performance across age subgroups categorized as under 6 months versus 6 to 12 months, gender, and clinical risk factors using chi-square tests. Fisher's exact test was employed where cell frequencies fell below five. A two-tailed p-value threshold of 0.05 defined statistical significance throughout all analyses.

Results

Participant Characteristics

The study enrolled 164 infants with clinically suspected hydrocephalus. Demographic and clinical characteristics are summarized in Table 1. Participants had a mean age of 5.8 months (SD = 3.4), with male infants predominating (63.4%, n=104). Preterm birth was documented in 54.3% (n=89) of cases, and 43.9% (n=72) experienced birth asphyxia. Perinatal infections affected 41.5% (n=68) of the cohort, while maternal comorbidities were present in 45.7% (n=75) of cases.

Table 1. Baseline Characteristics of Study Participants (n = 164)

Characteristic	Value
Age (months), mean ± SD	5.8 ± 3.4
Weight (kg), mean ± SD	6.2 ± 2.1
Male, n (%)	104 (63.4)
Preterm birth, n (%)	89 (54.3)
Birth asphyxia, n (%)	72 (43.9)
Perinatal infection, n (%)	68 (41.5)
Maternal comorbidity, n (%)	75 (45.7)
Family history, n (%)	68 (41.5)

Diagnostic Performance of Ultrasonography

Computed tomography identified hydrocephalus in 48.8% (n=80) of infants. Ultrasonography demonstrated the diagnostic performance shown in Table 2:

- Sensitivity: 88.8% (95% CI: 80.1–94.0)
- Specificity: 52.4% (95% CI: 41.6–62.9)
- Positive Predictive Value (PPV): 64.0% (95% CI: 54.5–72.4)

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- Negative Predictive Value (NPV): 83.0% (95% CI: 70.8–90.8)
- Overall Accuracy: 70.1% (95% CI: 62.6–76.8)

The false positive rate for ultrasonography was 47.6% (40/84), while the false negative rate was 11.2% (9/80).

Table 2. Diagnostic Accuracy of Ultrasonography Versus Computed Tomography (n=164)

Ultrasonography	CT Positive	CT Negative	Total
Positive	71 (TP)	40 (FP)	111
Negative	9 (FN)	44 (TN)	53
Total	80	84	164

TP: True Positive; FP: False Positive; FN: False Negative; TN: True Negative

Stratified Analysis by Age

Diagnostic accuracy varied significantly across age groups (Table 3). Ultrasonography exhibited higher sensitivity (91.7% vs. 85.7%) and NPV (88.9% vs. 77.8%) in infants aged <6 months compared to those ≥6 months. However, specificity was substantially lower in younger infants (41.7% vs. 65.0%).

Table 3. Age-Stratified Diagnostic Performance of Ultrasonography

Metric	<6 Months (n=96)	≥6 Months (n=68)	p-value
Sensitivity	91.7% (66/72)	85.7% (12/14)	0.021*
Specificity	41.7% (10/24)	65.0% (33/54)	0.003*
PPV	80.0% (66/82)	41.4% (12/29)	<0.001*
NPV	88.9% (10/14)	77.8% (33/39)	0.045*
Accuracy	79.2% (76/96)	66.2% (45/68)	0.038*

Chi-square test; $p<0.05$ significant

Gender-Based Analysis

Male infants (n=104) showed higher sensitivity (90.0% vs. 85.7%) but lower specificity (45.5% vs. 64.3%) compared to females (n=60). Diagnostic accuracy was comparable between genders (72.1% vs. 66.7%, p=0.214).

Influence of Clinical Risk Factors

Prematurity significantly impacted ultrasonography performance. Preterm infants (n=89) demonstrated lower specificity (38.1% vs. 68.8%, p<0.001) and PPV (58.2% vs. 72.7%, p=0.012) compared to term infants. Birth asphyxia and perinatal infections did not significantly alter diagnostic accuracy (p>0.05).

Discussion

This study provides a comprehensive evaluation of cranial ultrasonography's diagnostic accuracy for hydrocephalus in infants under 12 months, using computed tomography as the reference standard. Our findings demonstrate that ultrasonography achieves high sensitivity (88.8%) but moderate specificity (52.4%), supporting its role as an effective screening tool while highlighting critical limitations in confirmatory diagnosis. The overall accuracy of 70.1% aligns with prior research reporting 60–80% accuracy for microtomography in pediatric populations (Ikram et al., 2020; Kumar et al., 2016), though our specificity falls below the 58.1% reported in similar cohorts (Ikram et al., 2020). This discrepancy may stem from our inclusion of older infants (up to 12 months) with progressive fontanelle closure, which reduces acoustic window quality and measurement precision.

The stratified analysis revealed significant age-dependent variation in ultrasonography's diagnostic capabilities. Infants under six months exhibited superior sensitivity (91.7%) and negative predictive value (88.9%), these age-dependent variations in ultrasonography performance aligns with recent findings emphasizing that cranial ultrasound provides optimal ventricular visualization through open fontanelles, with diminishing reliability as fontanelles ossify (Gonţ et al., 2025) and consistent with studies emphasizing optimal ventricular visualization through open fontanelles (Bhat & Bhat,

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2014). However, specificity plummeted to 41.7% in this subgroup, likely reflecting overdiagnosis of borderline ventricular dilation in developing brains. Conversely, infants aged 6–12 months showed improved specificity (65.0%) but reduced sensitivity (85.7%), suggesting diminishing diagnostic reliability as fontanelles ossify.

Prematurity emerged as another critical modifier, with preterm infants demonstrating significantly lower specificity (38.1% vs. 68.8%, $p<0.001$) and PPV (58.2% vs. 72.7%, $p=0.012$). This aligns with evidence that periventricular leukomalacia and residual germinal matrix hemorrhage in preterm brains may mimic hydrocephalic ventricular patterns (Tabrizi et al., 2017). Gender-based differences were less pronounced, though reduced specificity in males (45.5% vs. 64.3% in females) warrants further investigation into potential neuroanatomical variations.

The high sensitivity and NPV (83.0%) support ultrasonography's utility as an initial screening modality, particularly in resource-limited settings where CT accessibility remains constrained. Its radiation-free nature addresses critical safety concerns in pediatric neuroimaging, as cumulative CT exposure increases lifetime malignancy risk by 0.1–1.0% per examination (Gaillard et al., 2024). However, the low specificity and high false-positive rate (47.6%) necessitate confirmatory CT for positive ultrasonography results to avoid unnecessary surgical interventions (Lopez & Nguyen, 2022). Also, recent comparative studies demonstrate that while computed tomography excels in detecting lateral ventricle involvement (94.9% vs 84.6% for MRI), magnetic resonance imaging proves superior for identifying specific pathologies such as spina bifida, absence of corpus callosum, and Arnold-Chiari syndrome (Nadeem et al., 2025). Current pediatric hydrocephalus diagnosis relies primarily on symptomatology combined with brain imaging, with ultrasonography, CT, or MRI warranted based on clinical presentation and fontanelle accessibility (Jadhav et al., 2024).

Several limitations warrant acknowledgment. First, the single-center design may limit generalizability, though the sample size (n=164) exceeds most regional studies. Second, ultrasonography's operator dependency introduces potential measurement variability, despite standardized protocols and experienced radiologists. Third, the absence of MRI correlation precludes comparison with the emerging gold standard for etiological diagnosis. Finally, long-term clinical follow-up was not incorporated to assess false negatives' neurological outcomes.

Prospective multicenter studies integrating MRI and serial neurodevelopmental assessments are needed to validate age-specific diagnostic thresholds. The clinical significance of accurate hydrocephalus diagnosis extends beyond immediate management, with standardized screening approaches and algorithmic classification systems proving essential for reducing diagnostic variability between practitioners (Miller et al., 2021). Contemporary evidence supports cranial ultrasonography as a valuable, non-invasive diagnostic tool that enables bedside evaluation and repeated monitoring without radiation exposure concerns (Kaleemullah et al., 2025). Machine learning algorithms show promise in automating ventricular measurements to reduce operator bias (Tabrizi et al., 2017). In resource-constrained regions, point-of-care ultrasonography training for pediatricians could enhance early detection while reserving CT for confirmation.

Conclusion

Cranial ultrasonography demonstrates excellent sensitivity (88.8%) and negative predictive value (83.0%) for hydrocephalus detection in infants under 12 months, supporting its role as a frontline screening tool. However, its suboptimal specificity (52.4%) and significant false-positive rate, particularly in preterm and young infants, necessitate confirmatory CT for definitive diagnosis. These findings advocate for a tiered diagnostic approach: ultrasonography for initial screening followed by CT for positive cases, balancing diagnostic accuracy with radiation safety in pediatric populations. Future research should focus on refining age-specific ultrasonographic criteria and developing standardized training protocols to optimize diagnostic reliability.

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