Research Article

Umbilical Cord Arterial Blood Gas Parameters as Predictors of Hypoxic-Ischemic Encephalopathy Severity in Neonates with Low Apgar Scores

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Abstract

Background: Hypoxic-ischemic encephalopathy (HIE) severity following perinatal asphyxia is graded by clinical criteria (Sarnat stages I–III) and strongly influences outcomes. Umbilical arterial blood gases, including pH and base deficit (BD), reflect the degree of fetal acidemia from intrapartum hypoxia.

Objectives: To evaluate whether umbilical arterial pH and BD at birth predict the subsequent HIE in term neonates with 5-minute Apgar scores ≤5.

Methods: In this prospective observational cohort of term neonates (gestational age ≥37 weeks) with 5-minute Apgar ≤5, umbilical arterial pH and BD were recorded at birth (double-clamped cord samples). Neonates were classified by Sarnat criteria. Mean pH and BD across HIE groups were compared (ANOVA), and correlations with HIE stage were assessed (Spearman's ρ).

Results: Eighty infants met inclusion criteria. HIE classification was: None (n=40), Stage I (n=20), Stage II (n=17), Stage III (n=13). Mean umbilical arterial pH progressively decreased with increasing HIE severity; mean BD increased (both ANOVA $p<0.001$). pH and BD showed strong monotonic relationships with HIE stage (Spearman's $\rho = -0.94$ and +0.80, respectively; both $p<0.001$).

Conclusion: In term neonates with low 5-minute Apgar scores, lower cord arterial pH and higher BD were strongly associated with more severe HIE, supporting the clinical value of cord blood gas analysis for early risk stratification.

Keywords: Hypoxic-Ischemic Encephalopathy, Umbilical Artery Blood Gas, Base Deficit, Apgar Score, Term Neonates

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Introduction

Birth asphyxia remains a leading cause of neonatal morbidity and mortality worldwide.[1] It results from impaired gas exchange before, during, or immediately after birth, leading to hypoxia, hypercapnia, and metabolic acidosis.[2] Despite advancements in fetal monitoring, a critical time lag persists between the detection of fetal heart rate (FHR) abnormalities and the delivery of an asphyxiated neonate. In a landmark study, Cynthia M et al. demonstrated that 75% of infants diagnosed with neonatal encephalopathy (NE) had abnormal cardiotocographic readings at least one hour before birth indicating the window of opportunity for intervention that if utilized effectively, can lead to reduction of adverse outcomes.[3] Another observational study by Hege Langli Ersdal's team highlighted the correlation of intermittent detection of FHR abnormalities with increased risks of fresh stillbirths, birth asphyxia, and early neonatal deaths, particularly in limited-resource settings.[4] This delay can compromise neonatal circulation, increasing the risk of severe hypoxic-ischemic encephalopathy (HIE) and long-term neurodevelopmental impairment.

Umbilical cord blood gas analysis has emerged as a valuable objective marker for assessing neonatal vitality at birth.[5] Low umbilical artery pH (pHUA) is an established indicator of hypoxia, while base deficit (BDUA) provides a more linear measure of metabolic acidosis.[6] The distinction between metabolic and respiratory acidosis is critical in determining the timing and severity of an

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asphyxial event. While isolated respiratory acidosis may be transient and self-resolving, metabolic acidosis indicates prolonged anaerobic metabolism and a greater risk of organ injury.[7]

The National Health Service (NHS) recommends cord blood gas sampling in all births when possible and mandates in specific clinical scenarios, including the high-risk deliveries such as emergency cesarean sections, instrumental births, and cases involving meconium-stained liquor or maternal pyrexia. These guidelines emphasize that paired arterial and venous samples to offer a comprehensive view of the neonate's metabolic condition, enabling the physician in the early detection of perinatal asphyxia and necessitating the timely clinical interventions.[8]

Retrospective analysis from Mardan Medical Complex showed that birth asphyxia accounted for 15.7% of all neonatal admissions, another study highlighting the overall observed prevalence of birth asphyxia was 17.9% at Khyber Teaching Hospital Peshawar.[9,10] Descriptive analysis done at Services hospital Lahore demonstrated that out of 150 neonates admitted with birth asphyxia, 51 (34%) succumbed to the condition, while 99 (66%) survived. Notably, 69 (46%) of these neonates developed neurological complications, underscoring the long-term impact of perinatal asphyxia beyond immediate survival, these numbers reflect the substantial burden of birth asphyxia and highlight the urgent need for early diagnostic tools and interventions.[11] At Lahore General Hospital, routine umbilical cord arterial sampling had not been systematically evaluated for its predictive value in HIE staging. This study prospectively assessed the association between umbilical arterial pH and BD at birth and subsequent HIE severity (Sarnat stages) in term neonates with low Apgar scores, to inform early risk stratification and clinical decision-making.

Methods

This prospective observational cohort study was conducted in the Neonatology Department of Lahore General Hospital between December 2024 and April 2025. Ethical approval was obtained from the Institutional Review Board prior to commencement. A total of 80 term neonates (gestational age ≥37 weeks) with a 5-minute Apgar score of ≤5 were consecutively enrolled. Neonates with major congenital anomalies or incomplete cord sampling were excluded. Immediately after birth, umbilical arterial blood was obtained from double-clamped cord segments, and pH and base deficit (BD) were measured using standard laboratory protocols. Lactate levels were recorded when available. These parameters were used to differentiate between respiratory and metabolic acidosis and to estimate the severity of hypoxia.

Clinical and perinatal data were collected using a standardized checklist to ensure consistency. The checklist included Apgar scores at 1 and 5 minutes, need for resuscitation, presence of meconium-stained liquor, neurological findings (tone, level of consciousness, seizures, reflexes), respiratory support requirements (mechanical ventilation, CPAP, or supplemental oxygen), and neonatal outcomes such as NICU stay duration, mortality, and short-term complications. Each neonate underwent a detailed neurological examination, and HIE severity was classified according to Sarnat staging into four groups: no encephalopathy, HIE stage I, HIE stage II, and HIE stage III.[12]

Data were analyzed using IBM SPSS Statistics for Windows, Version 26.0 (Released 2019; IBM Corp., Armonk, New York, United States). Mean pH and BD values across HIE groups were compared using one-way analysis of variance (ANOVA). Because HIE severity is an ordinal variable and cord blood gas parameters are continuous, Spearman's rank correlation coefficient (ρ) was used to assess the strength and direction of monotonic associations between pH, BD, and HIE stage. A p-value of <0.05 was considered statistically significant.

Results

A total of 80 term neonates with 5-minute Apgar scores ≤5 were included in the study. The mean gestational age of the cohort was 39.0 ± 1.1 weeks (range 37–41 weeks), and 46% of the infants were female. Birth weights were comparable across groups, and there were no statistically significant differences in baseline demographic characteristics between neonates who developed hypoxic-ischemic encephalopathy (HIE) and those who did not. By Sarnat staging, 40 infants (50%) exhibited no encephalopathy, 20 (25%) were classified as HIE stage I, 17 (21.25%) as HIE stage II, and 13 (16.25%) as HIE stage III.

Umbilical arterial blood gas analysis revealed a clear gradient in both pH and base deficit (BD) values across the four groups. Infants without HIE had the highest mean pH (7.29 ± 0.05) and the lowest mean BD (−2.8 ± 1.4 mmol/L), indicating minimal acidemia. In contrast, neonates with severe HIE (stage III) demonstrated the lowest mean pH (6.71 ± 0.06) and the highest mean BD (−15.8 ± 1.4 mmol/L), consistent with profound metabolic acidosis. Intermediate values were observed in stages I and II, with mean pH levels of 7.10 ± 0.07 and 6.89 ± 0.07, and mean BD values of −6.8 ± 2.7 and −11.5 ± 2.1 mmol/L, respectively. These differences were statistically significant across groups (ANOVA $p<0.001$; Table 1).

Correlation analysis further confirmed the strength of association between cord blood gas parameters and HIE severity. Spearman's rank correlation demonstrated a strong inverse relationship between pH and HIE stage ($\rho = -0.94$, $p<0.001$), indicating that lower pH values were consistently associated with higher stages of encephalopathy. Conversely, BD showed a strong positive

correlation with HIE stage (ρ = +0.80, p<0.001), reflecting that greater metabolic acidosis was linked to more severe neurological impairment. These monotonic relationships highlight the predictive value of cord arterial blood gas analysis in stratifying risk among neonates with low Apgar scores (Table 2).

The magnitude of differences observed was clinically meaningful. The nearly 0.6 unit decline in mean pH from infants without HIE to those with stage III disease underscores the severity of acidemia in the latter group. Similarly, the progressive rise in BD across stages reflects worsening metabolic derangement, which aligns with the pathophysiological progression of hypoxic-ischemic injury. The consistency of these findings across the cohort suggests that cord arterial pH and BD are robust markers for early identification of neonates at risk of moderate-to-severe HIE.

Table 1: *Umbilical Arterial Blood Gas Parameters by HIE Stage (mean ± SD)*

HIE Stage	n	pH (mean ± SD)	Base Deficit (mmol/L)	p (ANOVA)
None	40	7.29 ± 0.05	-2.8 ± 1.4	<0.001
HIE I	20	7.10 ± 0.07	-6.8 ± 2.7	<0.001
HIE II	17	6.89 ± 0.07	-11.5 ± 2.1	<0.001
HIE III	13	6.71 ± 0.06	-15.8 ± 1.4	<0.001

Table 2: *Correlation of Umbilical Arterial pH and Base Deficit with HIE Severity*

Variable	Spearman's ρ	p-value
pH vs. HIE stage	–0.94	<0.001
Base deficit vs. HIE stage	0.8	<0.001

Discussion

Umbilical cord arterial pH and base deficit (BD) emerged in this study as valuable predictors of HIE severity in neonates with low Apgar scores. The strong inverse correlation between pH and HIE stage, and the direct correlation between BD and HIE severity, highlight the pathophysiological link between metabolic acidosis and neurological injury. These findings reinforce the clinical utility of cord blood gas analysis as an objective measure of neonatal metabolic status, especially in the context of perinatal asphyxia.

The results are consistent with prior literature demonstrating that cord blood gas parameters can stratify risk for HIE. One study reported significantly lower mean pH values in neonates with mild to moderate HIE compared to those without encephalopathy, a finding corroborated by our cohort where infants with stage II and III HIE had progressively lower pH values (6.89 and 6.71, respectively) compared to those without HIE (7.29). Similarly, BD values in our study increased in parallel with HIE severity, echoing the association between metabolic acidosis and neurological compromise described by Bhat et al..[13] This consistency across studies strengthens the evidence base for incorporating cord arterial blood gas analysis into routine neonatal assessment protocols.

Compared to Apgar scores alone, umbilical cord arterial blood gas (UCABG) analysis offers greater specificity and sensitivity in diagnosing neonatal asphyxia. Several studies have highlighted the limitations of Apgar scoring, particularly its subjectivity and variability across observers. In contrast, UCABG provides quantifiable

biochemical data that directly reflect the neonate's metabolic condition. Cai et al. demonstrated that UCABG had higher diagnostic accuracy than Apgar scores in identifying fetal distress, and our findings support this by showing that cord pH and BD values were strongly predictive of subsequent HIE staging.[14] Thus, while Apgar scores remain useful for immediate clinical assessment, cord blood gas analysis adds a critical layer of objectivity and prognostic value.[15]

Beyond diagnostic accuracy, UCABG carries prognostic implications for neonatal outcomes. De Bernardo et al. found that low cord pH values were associated with increased risk of respiratory distress syndrome (RDS), with a cut-off of 7.12 yielding moderate sensitivity and specificity. Our study similarly demonstrated that lower pH values correlated with more severe HIE, suggesting that cord blood gas analysis can identify neonates at risk not only for encephalopathy but also for other complications of perinatal hypoxia.[16] This reinforces the role of UCABG in guiding early clinical decision-making, such as timely NICU admission, initiation of respiratory support, and consideration of neuroprotective interventions.

In addition, UCABG has been shown to predict low Apgar scores themselves. Elham et al. reported that cord pH ≤7.2 and abnormal base excess were significant predictors of low first-minute Apgar scores.[17] Our study focused on neonates already identified as high-risk by low Apgar scores, but the strong correlations we observed between cord blood gas parameters and HIE severity suggest that UCABG could also serve as an early screening tool in broader neonatal populations. This dual role—predicting both Apgar outcomes and subsequent neurological staging—underscores its versatility in perinatal care.

The clinical implications of these findings are substantial. Routine cord blood gas analysis, particularly in neonates with low Apgar scores, can enhance risk stratification and optimize resource allocation in neonatal intensive care units. Early identification of infants at risk for moderate-to-severe HIE allows clinicians to prioritize interventions such as therapeutic hypothermia, which has been shown to improve neurodevelopmental outcomes when initiated promptly. Although therapeutic hypothermia was not available at our study center, the predictive value of cord blood gas analysis remains critical for informing clinical decisions and advocating for the adoption of such interventions in resource-limited settings.

Our study also highlights the importance of differentiating between respiratory and metabolic acidosis. While respiratory acidosis may be transient and self-resolving, metabolic acidosis reflects prolonged hypoxia and anaerobic metabolism, carrying greater risk of organ injury. By measuring both pH and BD, cord blood gas analysis provides a more comprehensive picture of the neonate's metabolic state, enabling clinicians to distinguish between benign and pathological acidemia. This distinction is vital for tailoring management strategies and counseling families about prognosis.

Limitations of our study include its single-center design and modest sample size (n=80), which may restrict generalizability. Additionally, we did not account for all potential confounders, such as details of resuscitation or maternal risk factors, which could influence neonatal outcomes. Nevertheless, the large effect sizes observed and the consistency of our findings with prior studies suggest that the associations are robust. Future research should expand to multicenter cohorts, incorporate additional biomarkers such as lactate and EEG findings, and evaluate the impact of integrating cord blood gas analysis into standardized neonatal protocols.

Our findings demonstrate that umbilical cord arterial pH and base deficit are reliable predictors of HIE severity in neonates with low Apgar scores. By providing objective biochemical data that correlate strongly with neurological staging, cord blood gas analysis enhances early risk stratification, supports clinical decision-making, and has the potential to improve neonatal outcomes. These results add to the growing body of evidence advocating for routine cord blood gas sampling in high-risk deliveries, particularly in settings where timely intervention can make a critical difference in survival and long-term neurodevelopment.

Conclusion

This prospective observational study demonstrated that umbilical cord arterial pH and base deficit at birth are reliable predictors of HIE severity in term neonates with low Apgar scores. Lower pH and higher BD were strongly associated with higher Sarnat stages, supporting routine umbilical arterial blood gas analysis to improve early risk stratification and inform clinical decision-making. Future work should expand to multicenter cohorts and integrate additional biomarkers (e.g., lactate, EEG) to refine prognostic models.

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RMK, NA: Involved in design of study, revise critically and final review & editing.

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