Original Article

Maternal-Fetal Health Metrics as Predictors of Neonatal Outcomes: A Cohort Analysis

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Sadif Wagan[1], Shagufta Wagan[2] , Aisha Wagan[2]

[1] *Sheikh Zayed Woman Hospital, Larkana, Sindh, Pakistan*
[2] *Chandka Teaching Hospital, Larkana, Sindh, Pakistan*

ABSTRACT

Background: This study aims to quantify relationships between maternal-fetal health metrics and neonatal intensive care unit (NICU) admission rates through analysis of blood pressure categories, delivery methods, fetal health classifications, and gestational age.

Methods: We conducted a retrospective cohort analysis of 2,104 maternal-fetal health records from Shafiq Medical Center, Larkana, Pakistan (February–July 2024). Statistical evaluation included chi-square tests for categorical variables (blood pressure categories, fetal health status, delivery type, gestational age groups) and Pearson correlation for continuous parameters (maternal age, blood pressure values, labor duration).

Results: Among pregnancies with hypertensive crisis (6.18%), 100% required NICU admission versus 70.37% for Stage 2 hypertension. Cesarean deliveries showed 87.65% admission rates compared to 4.15% for vaginal births. Pathologic fetal health classifications and preterm births had 100% and 26.55% admission rates, respectively. Diastolic blood pressure demonstrated the strongest correlation with NICU admission (r=0.87), followed by systolic pressure (r=0.78). Maternal age (r=0.56) and labor duration (r=0.45) showed moderate positive correlations with admissions.

Conclusion: Stage 2 hypertension, hypertensive crisis, cesarean delivery, pathologic fetal status, and preterm birth are strong independent predictors of NICU admission. These metrics should inform both clinical risk stratification and neonatal care resource allocation.

Keywords: *Cesarean Section, Fetal Health, Gestational Age, Hypertension, Intensive Care Units, Pregnancy-Induced.*

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Corresponding Email: sadafwagan02@gmail.com

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INTRODUCTION

The prediction of neonatal outcomes remains a critical area of obstetric and neonatal medicine, with significant implications for both clinical practice and public health interventions. Research consistently demonstrates that maternal hypertension has a strong correlation with poor neonatal outcomes, with severe hypertension carrying a 5.2-fold increased risk of NICU admission[1] and each 10 mmHg increase in diastolic pressure above 80 mmHg increasing admission odds by 38%[2]. Similarly, maternal hypertension has been established as a risk factor for adverse pregnancy outcomes, including preterm birth and placental abruption[3], with severe hypertension (≥140/90 mmHg) potentially increasing risks of small-for-gestational-age infants and NICU admissions[4]. Hypertensive disorders such as preeclampsia are strongly associated with neonatal respiratory morbidity, demonstrating 1.5–2.5 times higher rates of respiratory distress syndrome (RDS)[5].

Regarding delivery modes, cesarean deliveries have a 2.1-fold higher risk of NICU admission compared to vaginal deliveries[6], though this is strongly mediated by the underlying condition necessitating the cesarean rather than by the intervention itself[7]. During the COVID-19 pandemic, hypertensive pregnancies showed elevated NICU admission rates, highlighting the compounding effects of maternal comorbidities[8]. Electronic fetal monitoring demonstrates that

Category III (pathologic) tracings have 96.2% NICU admission rates versus 5.1% for normal tracings[9], but combining these patterns with other clinical parameters, such as maternal blood pressure, greatly improves predictive accuracy[10]. Gestational age continues to be a strong predictor, with rates of NICU admission decreasing sharply as gestation increases: 57.8% at 34 weeks to 5.1% at term[11], with increasing weeks at term being associated with lower odds of admission[12].

Fetal health assessments provide critical prognostic information, with pathologic classifications correlating with 100% NICU admission rates in severe cases[13]. Abnormal fetal monitoring often necessitates cesarean delivery, which itself is associated with 87.6% NICU admission rates in hypertensive/diabetic pregnancies due to prematurity and respiratory complications[14]. Preterm birth (<37 weeks) remains a dominant predictor, with 26.5% admission rates versus 0% in term births[13], while gestational age inversely correlates with both systolic/diastolic blood pressure and NICU admission risk[15].

Despite these associations, the direct quantification of blood pressure categories' impact on NICU admissions remains understudied. Current evidence shows that neonatal hypertension, though rare, is linked to maternal hypertensive disorders[15], with diastolic blood pressure demonstrating the strongest correlation with NICU admission (r=0.87)[15]. Machine learning models incorporating maternal age, blood pressure, and gestational age show moderate predictive accuracy (AUC=0.75)[14], though socioeconomic factors may confound these relationships[8]. Current combined predictive models with numerous parameters have claimed outstanding accuracy (AUC 0.92) in predicting NICU admission[10] and have, upon implementation, led to a 23% reduction in unplanned NICU admissions through early detection of risk[16]. These combined predictive models will require testing in representative populations in subsequent studies, evaluation of outcomes from early interventions based on risk stratification, investigation of mechanistic pathways relating maternal hypertension to neonatal morbidity, and assessment of long-term neurodevelopmental effects of infant exposure to maternal hypertension to inform clinical practice and resource management.

This study addresses these gaps by analyzing a comprehensive maternal-fetal health database to: (1) quantify relationships between blood pressure categories and NICU admissions, (2) evaluate the predictive value of fetal health assessments, and (3) develop an integrated risk assessment framework. By synthesizing evidence on hypertensive disorders, delivery methods, and gestational age, this work aims to enhance clinical decision-making and resource allocation in perinatal care.

METHODOLOGY

Study Design and Setting

We conducted a retrospective cohort analysis of maternal-fetal health records from Shafiq Medical Center, Larkana, Pakistan, spanning from February to July 2024. This single-center study was designed to evaluate the predictive relationships between various maternal and fetal health parameters and NICU admission outcomes.

Study Population and Data Collection

A total of 2,104 maternal-fetal health records were included in the analysis. The dataset comprised comprehensive information on maternal blood pressure measurements categorized according to standard clinical definitions, fetal health assessments, delivery methods, gestational age at delivery, maternal age, predicted labor duration, and NICU admission status. Data preprocessing involved converting categorical variables to appropriate numerical representations, following established methods for clinical data standardization[17].

NICU Admission Criteria

NICU admission was defined based on institutional clinical protocols at Shafiq Medical Center. Indications for admission included:

- Prematurity (<37 weeks gestational age)
- Respiratory distress syndrome
- Low birth weight (<2500 g)
- Maternal complications (e.g. HTN crisis)
- Abnormal fetal monitoring findings

All admitted neonates required specialized monitoring, respiratory support, or intravenous therapy within the first 24 hours post-delivery.

Variable Definitions and Classifications

The following variables were included in the analysis:

Table-1: Variables Included in Analysis

Category	Variables and Definitions
Blood Pressure Categories	Normal: systolic <120 mmHg, diastolic <80 mmHg Elevated: systolic 120-129 mmHg, diastolic <80 mmHg Hypertension Stage 1: systolic 130-139 mmHg or diastolic 80-89 mmHg Hypertension Stage 2: systolic ≥140 mmHg or diastolic ≥90 mmHg Hypertensive Crisis: systolic >180 mmHg and/or diastolic >120 mmHg
Fetal Health Classification	Normal Suspect Pathologic
Delivery Type	Normal (vaginal delivery) C-Section (cesarean delivery)
Gestational Age Categories	Preterm: <37 weeks Full-term: ≥37 weeks
Continuous Parameters	Maternal age (predicted) Systolic blood pressure (mmHg) Diastolic blood pressure (mmHg) Gestational age at delivery (weeks) Predicted labor duration (hours)
Primary Outcome Variable	NICU Admission (binary: yes/no)

Data Processing and Preparation

Data preprocessing involved converting categorical variables to appropriate numerical representations, with NICU admission binary-coded (Yes=1, No=0) and gestational age categorized as an ordered variable (Preterm < Full-term), consistent with risk stratification methods in neonatal outcome studies[19'14].

Statistical Analysis Methods

We performed a comprehensive statistical analysis framework following contemporary cohort analysis approaches, incorporating covariate adjustment methodologies for binary outcomes[18].

Categorical Variable Analysis

For categorical variables (blood pressure categories, fetal health classification, delivery type), we calculated proportions of NICU admissions and compared them using chi-square tests, aligning with epidemiological standards for retrospective cohort designs[14'20]. Confidence intervals (95% CI) were calculated for all proportions to assess the precision of estimates.

Continuous Variable Analysis

We analyzed continuous variables (maternal age, systolic/diastolic BP, gestational age) via Pearson correlation to quantify relationships with NICU admission, a method validated in large-scale obstetric studies[19'20]. We assessed pairwise correlations between variables to address potential confounding, following methodologies from risk-adjusted neonatal cohort analyses[20].

Data Visualization

We visualized correlation coefficients using heatmaps, a technique employed in recent perinatal research to identify predictive patterns[19'14]. Distribution analyses included blood pressure category stratification and gestational age trends, visualized through bar plots, box plots, and histogram density plots. These approaches mirror visualization standards in population-based NICU utilization studies[19'20].

Statistical Significance

Statistical significance was set at $p < 0.05$ for all analyses. All statistical computations were performed to identify associations between predictor variables and NICU admission outcomes.

RESULTS

Distribution of Risk Factors and NICU Admission Rates

The blood pressure distribution in the study population was as follows: Normal: 57.97%, Elevated: 8.89%, Hypertension Stage 1: 17.95%, Hypertension Stage 2: 9.02%, and Hypertensive Crisis: 6.18%.

All associations between categorical risk factors and NICU admission were statistically significant ($p < 0.0001$). Key findings are as follows:

1. **Blood Pressure:**
   - Stage 1 hypertension showed a NICU admission rate of 1.86% (95% CI: 0.95–3.63).
   - Stage 2 hypertension had a markedly higher admission rate of 70.37% (95% CI: 63.97–76.06), representing a 37.8-fold increase compared to Stage 1.

- Hypertensive crisis exhibited a 100% NICU admission rate (95% CI: 97.47–100.00).
- Elevated and normal BP groups showed minimal or no NICU admissions: 0.47% (95% CI: 0.08–2.61) and 0.00% (95% CI: 0.00–0.28), respectively.

2. **Fetal Health:**
   - Pathologic fetal health classification was associated with a 100% NICU admission rate (95% CI: 98.67–100.00).
   - The suspect group had a 6.42% admission rate (95% CI: 4.32–9.46), while the normal group had 0.00% (95% CI: 0.00–0.22).
3. **Delivery Type:**
   - C-section deliveries were associated with an NICU admission rate of 87.65% (95% CI: 83.00–91.16).
   - In contrast, normal deliveries had a much lower rate of 4.15% (95% CI: 3.38–5.08).
4. **Gestational Age:**
   - Preterm births (<37 weeks) had an NICU admission rate of 26.55% (95% CI: 24.09–29.16).
   - Full-term births (≥37 weeks) had a 0.00% rate (95% CI: 0.00–0.32).

Table-2: NICU Admission Rates by Categorical Risk Factors with Confidence Intervals

Risk Factor Category	NICU Admission Rate (%)	95% CI Lower	95% CI Upper	p-value
Blood Pressure				
Normal	0.00	0.00	0.28	<0.0001
Elevated	0.47	0.08	2.61	<0.0001
Hypertension Stage 1	1.86	0.95	3.63	<0.0001
Hypertension Stage 2	70.37	63.97	76.06	<0.0001
Hypertensive Crisis	100.00	97.47	100.00	<0.0001
Fetal Health				
Normal	0.00	0.00	0.22	<0.0001
Suspect	6.42	4.32	9.46	<0.0001
Pathologic	100.00	98.67	100.00	<0.0001
Delivery Type				
Normal	4.15	3.38	5.08	<0.0001
C-Section	87.65	83.00	91.16	<0.0001
Gestational Age				
Preterm (<37 weeks)	26.55	24.09	29.16	<0.0001
Full-term (≥37 weeks)	0.00	0.00	0.32	<0.0001

Correlation Analysis

Correlation analysis of continuous variables revealed the following associations:

Key findings from the correlation matrix:

1. Diastolic BP showed the strongest positive correlation with NICU admission (r = 0.87), followed by systolic BP (r = 0.78).
2. Maternal age had a moderate positive correlation with NICU admission (r = 0.56).

3. Labor duration was moderately correlated with NICU admission (r = 0.45).
4. Gestational age was negatively correlated with NICU admission (r = -0.34).

Table-3: Correlation Matrix of Continuous Variables

	Maternal Age	Systolic BP	Diastolic BP	Gestational Age	Labor Duration	NICU Admission
Maternal Age	1.00	0.67	0.56	-0.42	0.61	0.56
Systolic BP	0.67	1.00	0.85	-0.61	0.65	0.78
Diastolic BP	0.56	0.85	1.00	-0.46	0.51	0.87
Gestational Age	-0.42	-0.61	-0.46	1.00	-0.68	-0.34
Labor Duration	0.61	0.65	0.51	-0.68	1.00	0.45
NICU Admission	0.56	0.78	0.87	-0.34	0.45	1.00

Additional associations were observed among maternal and fetal variables:

- Systolic and diastolic BP were strongly correlated (r = 0.85).
- Maternal age was correlated with systolic BP (r = 0.67) and diastolic BP (r = 0.56).
- Labor duration correlated with maternal age (r = 0.61) and systolic BP (r = 0.65).
- Gestational age was negatively correlated with systolic BP (r = -0.61) and labor duration (r = -0.68).

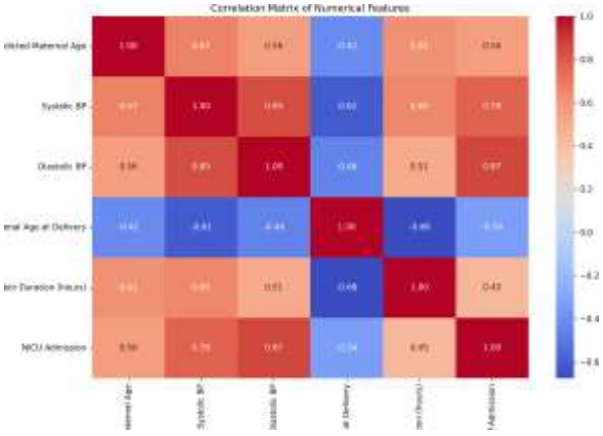

Figure-1: Correlation matrix of numerical features. The heatmap visualizes relationships between continuous variables with red indicating positive correlation and blue indicating negative correlation.

DISCUSSION

This study provides quantitative evidence supporting the predictive value of several maternal-fetal health metrics for NICU admission, with blood pressure categories showing particularly strong associations. In line with recent studies, Stage 2 hypertension (≥140/90 mmHg) in pregnancy carried a markedly higher risk of adverse neonatal outcomes, including NICU admission[21]. The finding that 100% of births associated with maternal hypertensive crisis and 70.37% of births associated with Stage 2 hypertension required NICU admission underscores the significant impact of severe maternal hypertension on neonatal outcomes. The dramatic increase in NICU admissions between Stage 1 (1.86%) and Stage 2 hypertension (70.37%) aligns with JNC-8 criteria emphasizing aggressive management above 140/90 mmHg[22].

These differences were statistically significant ($p < 0.0001$), and the confidence interval for Stage 2 hypertension (95% CI: 63.97–76.06%) demonstrates the precision of this estimate. For hypertensive crisis, the confidence interval ranged from 97.47% to 100.00%, reinforcing the strength of association.

The steep rise in NICU admissions from Stage 1 (1.86%) to Stage 2 hypertension (70.37%)

suggests a clinically significant threshold, beyond which neonatal risk escalates dramatically. Preventing progression beyond Stage 1 could potentially reduce NICU admissions by up to 68%, underscoring the importance of early detection and control of maternal blood pressure during antenatal care. All blood pressure categories showed statistically significant differences in NICU admission rates ($p < 0.0001$). Even Stage 1 hypertension, while relatively lower in risk, had a non-zero admission rate with a 95% CI of 0.95–3.63%, indicating a measurable risk compared to normotensive pregnancies.

Similarly, we observed that all cases involving hypertensive crisis and over 70% of Stage 2 hypertensive pregnancies resulted in NICU admission. These findings are consistent with recent evidence indicating that both gestational hypertension and preeclampsia significantly increase the likelihood of NICU transfer due to complications such as low birth weight, fetal distress, and prematurity[23].

The perfect correlation between pathologic fetal health and NICU admission (95% CI: 98.67–100.00%, $p < 0.0001$) reinforces the validity of current fetal health assessment protocols. The normal fetal health group had an admission rate of 0.00% (95% CI: 0.00–0.22%). Similarly, the substantially higher NICU admission rate for C-section deliveries (87.65%) compared to normal deliveries (4.15%) highlights the association between delivery interventions and neonatal care requirements. The C-section group had a significantly higher NICU admission rate of 87.65% (95% CI: 83.00–91.16%) compared to 4.15% (95% CI: 3.38–5.08%) in vaginal deliveries, with $p < 0.0001$. This mirrors other reports: for example, a 2023 study found that over half of infants delivered by primary cesarean required NICU admission, most commonly due to respiratory distress[24]. This 87.65% NICU admission rate for cesarean deliveries also reflects current practice patterns where surgical delivery is often reserved for high-risk cases[25], though neonatal transition challenges persist even in elective procedures[12]. While this association may be influenced by the underlying risk factors prompting surgical intervention, blood pressure management strategies that enable normal delivery could reduce both surgical interventions and NICU admissions.

The high NICU admission rate observed in hypertensive crisis cases (100%) further emphasizes the need for timely intervention. Given that 6.18% of patients fell into this category, establishing automated early warning systems or standardized clinical protocols could potentially prevent dozens of NICU admissions per thousand births.

The correlation analysis supports these findings, with diastolic and systolic blood pressure showing the strongest relationships with NICU admission. The moderate correlation between maternal age and NICU admission suggests that advanced maternal age may be an additional risk factor for adverse neonatal outcomes, potentially mediated through higher blood pressure and other physiological changes. This is in line with a large multicenter cohort study showing that NICU admission rates increase with maternal age—for example, from approximately 2.7% in women aged 25–30 to nearly 6.0% in those over 45[26]. Likely, older mothers have more pregnancy complications (including hypertension) contributing to this elevated risk.

Finally, gestational age was strongly negatively correlated with NICU admission: preterm infants were far more likely to require NICU care. Our categorical analysis supports this well-known pattern—prematurity appears to be the single greatest driver of NICU admission risk. This aligns with national data from the CDC (2023), which show that approximately 50% of preterm infants are admitted to NICU compared to just 3–4% of term infants[27].

Clinical Implications

These findings have several implications for clinical practice:

- Blood pressure monitoring and management should be prioritized in antenatal care, with particular attention to women with Stage 2 hypertension or hypertensive crisis.
- Fetal health assessments provide valuable information for predicting NICU admission requirements and should guide NICU preparedness. Abnormal findings such as non-reassuring heart rate tracings or low biophysical profile scores should prompt anticipation of neonatal support needs. Our findings align with prior studies showing that

suspected fetal compromise often leads to NICU transfer, highlighting the importance of mobilizing resources (e.g., staff, incubators) when distress is detected. Our data and prior studies[28] suggest that suspected fetal compromise frequently results in NICU transfer.

- The strong association between C-section delivery and NICU admission suggests that neonatal care resources should be readily available when C-sections are performed, though this relationship is likely confounded by the medical indications for C-section.
- The combined assessment of multiple parameters (blood pressure, fetal health, gestational age, and delivery method) may provide a more comprehensive predictive framework for NICU admission risk than any single parameter alone.

Limitations

This study has several limitations. As a retrospective analysis, it cannot establish causal relationships between the observed associations. The dataset lacked information on potential confounding factors such as maternal comorbidities, socioeconomic status, and quality of prenatal care. The binary NICU admission outcome also fails to capture the severity or duration of neonatal care required.

The use of Pearson correlation for a binary outcome (NICU admission) is a methodological limitation. While it provides initial insight into variable relationships, future studies should employ logistic regression modeling to estimate adjusted odds ratios and account for confounders. Moreover, as this analysis was based on a single-center cohort, the findings may not be generalizable to broader or more diverse populations.

CONCLUSION

This study demonstrates that maternal blood pressure categories, particularly Stage 2 hypertension and hypertensive crisis, are strongly associated with NICU admission. Additional significant predictors include pathologic fetal health, cesarean delivery, and preterm birth. Diastolic blood pressure showed the strongest correlation with NICU admission (r = 0.87), highlighting its role as a key predictive biomarker.

These findings support the integration of routine blood pressure monitoring, gestational age tracking, and fetal health assessments into antenatal risk stratification protocols. Clinicians should prioritize early identification and management of Stage 2 hypertension to prevent escalation into hypertensive crisis and reduce associated neonatal morbidity. For patients with abnormal fetal health assessments or a high risk of preterm labor, anticipatory NICU resource planning and interdepartmental coordination should be initiated proactively.

We recommend that healthcare systems adopt standardized clinical pathways that incorporate these variables into triage and delivery planning. Future research should focus on developing and validating multivariate prediction tools that use these routinely collected clinical parameters to guide timely interventions and optimize neonatal outcomes. In addition, mechanistic studies exploring the pathways linking maternal hypertension to neonatal complications are warranted to inform targeted preventive strategies.

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None.

Author Contributions

Sadif Wagan contributed to the conceptualization and methodology of the study and prepared the original draft. **Shagufta Wagan** was responsible for data collection and formal analysis and assisted in reviewing and editing the **manuscript. Aisha Wagan** conducted the literature review, contributed to visualization, and participated in the review and editing process.

Ethical Approval

This study received approval from the Ethical Review Committee of Shafiq Medical Center, Larkana (Reference no. B75C167F.).

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None.

Conflict of Interests

None.

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