



Maternal Hemodynamic and Nutritional Determinants of Neonatal Apgar score: The Role of Gestational Age, Body Mass Index, Hemoglobin, and Mean Arterial Pressure

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ABSTRACT

Background: The Apgar score is widely used to evaluate a newborn's physiological adaptation during the early transition from fetal to extrauterine life. Maternal physiological and nutritional conditions during pregnancy may influence neonatal outcomes. This study investigated the association between maternal hemodynamic parameters, nutritional status, and neonatal Apgar scores.

Method: A retrospective observational analytic study was performed using medical records from Margono Soekardjo Hospital collected in 2022. The study involved 190 mother–infant pairs selected through sequential sampling according to predetermined eligibility criteria. Gestational age, mean arterial pressure (MAP), hemoglobin concentration, and body mass index (BMI) were examined as independent variables, while the Apgar score served as the outcome variable. Statistical analyses included Spearman rank correlation and multiple linear regression, with statistical significance established at $p < 0.05$.

Result: Gestational age demonstrated a significant moderate positive relationship with Apgar score ($\rho = 0.549$; $p < 0.001$), indicating that increasing gestational age was associated with better neonatal adaptation. In contrast, maternal BMI was weakly and inversely correlated with Apgar score ($\rho = -0.329$; $p < 0.001$). No significant associations were observed between Apgar score and either hemoglobin level ($\rho = -0.016$; $p = 0.825$) or MAP ($\rho = -0.022$; $p = 0.765$). Regression analysis further identified gestational age ($\beta = 0.494$; $p < 0.001$) and BMI ($\beta = -0.167$; $p = 0.008$) as significant predictors of Apgar score, whereas hemoglobin concentration and MAP did not contribute significantly to the model.

Conclusion: Neonatal Apgar scores are primarily influenced by gestational age, with maternal BMI also showing a significant contribution. Conversely, maternal hemoglobin levels and mean arterial pressure were not associated with neonatal Apgar outcomes. These findings highlight the critical role of fetal maturity and maternal nutritional condition in supporting successful neonatal adaptation after birth.

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INTRODUCTION

Assessment of neonatal adaptation immediately following birth is essential for evaluating the effectiveness of the transition from intrauterine development to life outside the womb. Among the available assessment methods, the Apgar score is the most widely used because it provides a rapid evaluation of neonatal well-being through five parameters: pulse rate, breathing effort, muscle tone, reflex activity, and skin appearance. This scoring system serves not only as a guide for immediate clinical interventions, such as resuscitation, but also as an indicator of future neonatal outcomes, with lower scores being associated with increased risks of morbidity and mortality, particularly neurological complications (Kawakami et al., 2021).

Several studies have demonstrated that neonatal condition at birth is strongly influenced by maternal status during pregnancy. Maternal factors such as gestational age, nutritional status, hemoglobin levels, and hemodynamic condition play a fundamental role in ensuring adequate fetal oxygenation and nutrient supply during intrauterine development. Any disturbances in these parameters may reduce uteroplacental perfusion, leading to fetal hypoxia and consequently lowering the Apgar score at birth.

Neonatal asphyxia is a multifactorial condition influenced by maternal, fetal, and intrapartum factors. Adequate fetal oxygenation depends on optimal uteroplacental perfusion and maternal oxygen-carrying capacity. During pregnancy, physiological cardiovascular adaptations occur, including increased blood volume and cardiac output, to maintain adequate placental circulation. However, disturbances in maternal hemodynamic status, particularly abnormal mean arterial pressure (MAP), may impair uteroplacental blood flow and reduce oxygen delivery to the fetus. Chronic placental hypoperfusion can result in fetal hypoxia, metabolic acidosis, and poor neonatal adaptation after delivery, which is commonly reflected in low Apgar scores and abnormal umbilical cord pH values (Pérez et al., 2021).

Gestational age is another key determinant of neonatal adaptation. Preterm infants are characterized by immature lung development, insufficient surfactant production, and underdeveloped cardiorespiratory regulatory mechanisms, which limit their ability to adapt effectively to extrauterine life. As a result, preterm neonates are at higher risk of respiratory distress and neonatal asphyxia compared to term infants. Prematurity is also frequently associated with low birth weight and placental insufficiency, further compromising fetal oxygenation (Sakunti et al., 2024).

Maternal anemia also contributes significantly to impaired fetal oxygen delivery by reducing hemoglobin concentration and oxygen-carrying capacity. Sustained fetal hypoxia due to maternal anemia increases the risk of fetal distress, preterm birth, low birth weight, and neonatal asphyxia. In addition, maternal nutritional status, as reflected by Body Mass Index (BMI), plays an essential role in fetal growth and metabolic adaptation. Both low and high maternal BMI are associated with placental dysfunction and obstetric complications that may compromise fetal oxygenation and the neonatal transition after birth (Dubie et al., 2021).

Although previous studies have identified several determinants of neonatal asphyxia, most have examined maternal hemodynamic, hematological, and nutritional factors separately. Limited evidence has comprehensively analyzed the combined effects of gestational age, mean arterial pressure (MAP), maternal hemoglobin levels, and Body Mass Index (BMI) on neonatal outcomes. Therefore, this study aims to evaluate the simultaneous influence of maternal hemodynamic and nutritional determinants on neonatal Apgar scores as an indicator of neonatal asphyxia. The findings are expected to support early risk screening and improve preventive strategies in antenatal and perinatal care.

METHOD

Research Design

This research utilized a retrospective analytic observational design to evaluate the influence of maternal physiological and nutritional factors on neonatal condition at birth. Neonatal outcome was assessed using the Apgar score as the primary dependent variable. Maternal gestational age, mean arterial pressure (MAP), hemoglobin level, and body mass index (BMI) were included as independent variables. Secondary data were extracted from hospital medical records of mothers and newborns delivered at Margono Soekardjo Hospital throughout 2022. These variables were analyzed to identify their relationship with neonatal adaptation immediately after birth.

Participants

The study population consisted of all mother–newborn pairs recorded at Margono Soekardjo Hospital in 2022. The inclusion criteria were complete medical records of live singleton births with documented gestational age, maternal blood pressure, hemoglobin level, body weight, height, and neonatal Apgar score. The exclusion criteria included newborns with congenital anomalies, incomplete medical records, multiple pregnancies, and severe maternal chronic diseases that could affect fetal oxygenation.

Population and Sampling Method

The target population consisted of all mother–newborn pairs registered at Margono Soekardjo Hospital during 2022. The accessible population included all medical records that met the predetermined inclusion and exclusion criteria. A sequential sampling technique was applied, in which all eligible medical records within the study period were included until the required sample size was achieved.

The minimum sample size was determined based on the requirements for multivariable linear regression analysis, with a 95% confidence level and 80% statistical power. Assuming a medium effect size, the minimum required sample size was 172 participants. To anticipate potential incomplete data, an additional 10% was added, resulting in a final sample size of 190 participants.

Operational Definition of Variables

The neonatal Apgar score is defined as an assessment of neonatal adaptation based on five components: heart rate, respiratory effort, muscle tone, reflex irritability, and skin color, measured on a ratio scale. In this study, the Apgar score was treated as the dependent variable.

Gestational age is defined as the duration of pregnancy in completed weeks, calculated from the last menstrual period or confirmed by ultrasound examination. This variable was analyzed as ratio data.

Mean arterial pressure (MAP) is defined as the average arterial pressure during one cardiac cycle, calculated using the formula: $MAP = (\text{systolic blood pressure} + 2 \times \text{diastolic blood pressure}) / 3$, expressed in mmHg and analyzed as a ratio variable.

Maternal hemoglobin level is defined as the concentration of hemoglobin in maternal blood (g/dL), obtained from hospital laboratory examination results and analyzed as ratio data.

Maternal body mass index (BMI) is defined as body weight in kilograms divided by height in meters squared (kg/m^2) and was analyzed as a ratio variable.

Instrumentation

Data were extracted using a structured checklist from hospital medical records, including gestational age, blood pressure, hemoglobin level, body weight, height, and neonatal Apgar score. Mean arterial pressure (MAP) and body mass index (BMI) were calculated based on recorded clinical measurements. All data were obtained in accordance with standard hospital procedures for clinical and laboratory assessments.

Ethical Considerations

Approval to conduct this research was obtained from the Research Ethics Committee of Muhammadiyah University of Gombong (Reference No. 044.6/II.3.AU/F/KEPK/II/2023; February 14, 2023). The investigation relied exclusively on secondary data derived from patient medical records. Confidentiality was strictly maintained by de-identifying all records before data processing, thereby preventing the disclosure of any participant identities and ensuring compliance with ethical standards for research involving human data.

Data Analysis

Statistical procedures consisted of descriptive, correlation, and multivariable analyses. Since the continuous variables were not normally distributed, the results were expressed as medians accompanied by interquartile ranges and minimum–maximum values. Data normality was assessed using the Kolmogorov–Smirnov test. The relationship between each maternal factor and neonatal Apgar score was initially explored through Spearman correlation analysis. Variables meeting the screening criterion of $p < 0.25$, together with variables considered clinically meaningful according to existing evidence, were selected for inclusion in the multivariable analysis to identify independent determinants of neonatal outcomes.

The primary outcome of this study was the Apgar score at birth. Although the Apgar score is formally an ordinal variable ranging from 0 to 10, it was analyzed as a continuous outcome in the multivariable model. This approach has been widely applied in perinatal and epidemiological research because the Apgar score contains multiple ordered categories and often approximates a continuous scale when used to evaluate neonatal condition. Linear regression was selected to estimate the magnitude and direction of associations between maternal characteristics and neonatal Apgar score while allowing adjustment for potential confounding variables. Furthermore, the relatively large sample size ($n = 190$) supports the robustness of regression estimates, provided that model assumptions are adequately met.

To evaluate the appropriateness of the model, diagnostic tests were performed to assess linearity, homoscedasticity, normality of residuals, and multicollinearity. Multicollinearity was examined using tolerance and variance inflation factor (VIF), with VIF values < 10 indicating no significant multicollinearity among predictors.

Selection of variables for the multivariable model was based on both statistical and clinical considerations rather than solely on the results of the bivariate analysis. Maternal hemoglobin level and mean arterial pressure (MAP) were evaluated as candidate variables because of their established physiological relevance to maternal cardiovascular status, uteroplacental perfusion, fetal oxygen delivery, and neonatal outcomes. Although these variables were not significantly associated with Apgar score in the bivariate analysis, they were considered during model development. Variables that did not contribute meaningfully to the model, did not improve model fit, and remained non-significant after adjustment were excluded from the final parsimonious model.

All statistical analyses were performed using SPSS version 31. A p -value < 0.05 was considered statistically significant. The findings should be interpreted as measures of association rather than causal relationships.

Scope and Limitations of the Methodology

Retrospective design, single-center setting, and unmeasured confounders limit causal inference and generalizability.

RESULTS AND DISCUSSION

Results

A total of 190 mother–newborn data sets were analyzed to evaluate the relationship between maternal hemodynamic and nutritional determinants and neonatal adaptation, as measured by Apgar score.

Univariate Analysis

Table 1. Descriptive Statistics of Maternal Hemodynamic, Nutritional, and Neonatal Variables (n = 190)

Variable	Median (IQR)	Minimum	Maximum
Neonatal Apgar score	6.50 (3)	1	8
Maternal Body Mass Index (BMI) (kg/m ²)	24.34 (6.0)	20.2	38.2
Gestational Age (weeks)	34.50 (8)	21	42
Hemoglobin Level (g/dL)	11.70 (2.1)	8.3	15.7
Mean Arterial Pressure (MAP) (mmHg)	98.33 (32.7)	63.3	171.3

The results of the univariate analysis showed that the neonatal Apgar score had a median of 6.50 (IQR = 3), with a range of 1 to 8, indicating variability in neonatal adaptation during the early minutes of life. For maternal variables, body mass index (BMI) had a median of 24.34 kg/m² (IQR = 6.0), with a minimum of 20.2 kg/m² and a maximum of 38.2 kg/m², reflecting variation in maternal nutritional status ranging from normal to obese. Gestational age showed a median of 34.50 weeks (IQR = 8), with a range of 21 to 42 weeks, indicating variability from preterm to post-term pregnancies within the study sample. Maternal hemoglobin levels had a median of 11.70 g/dL (IQR = 2.1), with values ranging from 8.3 g/dL to 15.7 g/dL, reflecting variation from anemic to normal conditions among respondents. Meanwhile, mean arterial pressure (MAP) had a median of 98.33 mmHg (IQR = 32.7), with a range of 63.3 to 171.3 mmHg, indicating variability in maternal hemodynamic status from normal to elevated blood pressure levels. Overall, all variables showed heterogeneous distributions, reflecting variability in maternal and neonatal characteristics within the study population.

Normality Test

Kolmogorov–Smirnov test results showed that all study variables were not normally distributed ($p < 0.05$), as presented in Table 2. This indicates that the distribution of data deviates from normality.

Table 2. Kolmogorov–Smirnov Normality Test of Study Variables

Variable	p-value	Interpretation
Apgar score	0.000	Not Normal
BMI	0.001	Not Normal
Gestational Age	0.000	Not Normal
Hemoglobin	0.002	Not Normal
Mean Arterial Pressure (MAP)	0.000	Not Normal

Based on these results, bivariate analysis was performed using Spearman’s rank correlation, as this test does not require normally distributed data and is appropriate for skewed continuous variables. Although all variables were not normally distributed, data transformation was not performed in this study. This decision was based on the study objective, which focused on association and prediction using clinically interpretable variables in their original measurement scales.

For multivariate analysis, multiple linear regression was applied because it is relatively robust to violations of normality assumptions when the sample size is adequate ($n = 190$). In large

samples, parameter estimates tend to be stable due to the central limit theorem, particularly when other key assumptions such as linearity, homoscedasticity, and multicollinearity are satisfied.

In this study, regression analysis was conducted to explore predictive relationships rather than strict distributional inference. Therefore, preserving the original data scale was considered more appropriate to maintain clinical interpretability, especially for gestational age, BMI, hemoglobin level, and mean arterial pressure (MAP).

Furthermore, assumption testing confirmed that the regression model met the requirements of linearity, homoscedasticity, and absence of multicollinearity, supporting the validity of the model without the need for data transformation. This finding indicates that the data do not follow a normal distribution pattern, thereby justifying the use of non-parametric correlation analysis.

Bivariate Analysis

Spearman rank correlation was used to assess the relationship between maternal determinants and neonatal Apgar score.

Table 3. Spearman Rank Correlation Analysis between Maternal Determinants and Neonatal Apgar scores (n=190)

Variable	Spearman's rho	95% CI	p-value	Interpretation of Effect Size
Gestational Age	0.549	0.438 to 0.644	<0.001	Moderate positive correlation
Maternal Body Mass Index (BMI)	-0.329	-0.453 to -0.192	<0.001	Weak negative correlation
Hemoglobin Level (Hb)	-0.016	-0.162 to 0.131	0.825	No correlation
Mean Arterial Pressure (MAP)	-0.022	-0.168 to 0.125	0.765	No correlation

The results of Spearman's correlation analysis indicated that there were significant relationships between several maternal variables and the neonatal Apgar score. Gestational age showed a moderate positive correlation with Apgar score ($\rho = 0.549$; 95% CI: 0.438–0.644; $p < 0.001$), suggesting that higher gestational age is associated with better neonatal adaptation at birth.

In contrast, maternal body mass index (BMI) demonstrated a weak negative correlation with Apgar score ($\rho = -0.329$; 95% CI: -0.453 to -0.192; $p < 0.001$), indicating that an increase in BMI tends to be associated with a decrease in Apgar score, although the strength of the association is relatively weak. Meanwhile, hemoglobin (Hb) levels did not show a statistically significant relationship with Apgar score ($\rho = -0.016$; $p = 0.825$), nor did mean arterial pressure (MAP), which also showed no meaningful correlation ($\rho = -0.022$; $p = 0.765$).

Overall, gestational age was the strongest determinant of neonatal Apgar score, while BMI showed a weak inverse association. Hemoglobin and MAP were not significantly associated with neonatal outcomes in this study.

Multivariate Analysis

Table 4. Summary of Multiple Linear Regression Model

Model	R	R ²	Adjusted R ²	Std. Error of Estimate
1	0.556	0.309	0.301	1.714

To determine the factors independently associated with neonatal Apgar scores, a multiple linear regression model was developed. Gestational age and maternal BMI were selected as predictor variables in the final model, while hemoglobin concentration and MAP were excluded because they failed to demonstrate significant relationships during the bivariate analysis stage.

The findings shown in Table 4 indicate that the model achieved an R value of 0.556, reflecting a moderate predictive relationship between the selected maternal factors and neonatal condition at birth. The R² value

of 0.309 suggests that nearly one-third of the variation in Apgar scores could be accounted for by gestational age and BMI. Consequently, approximately two-thirds of the variation remained unexplained and may be related to other biological, obstetric, or environmental influences not assessed in the present study. The adjusted R^2 of 0.301 further supports the robustness of the model after correcting for the number of predictors. In addition, a standard error estimate of 1.714 indicates a relatively small average discrepancy between actual and predicted Apgar score values.

Table 5. ANOVA of Regression Model

Model	Sum of Squares	df	Mean Square	F	p-value
Regression	245.361	2	122.680	41.760	<0.001
Residual	549.355	187	2.938		
Total	794.716	189			

The ANOVA confirmed that the final regression model was statistically significant in predicting neonatal Apgar scores ($F = 41.760$; $p < 0.001$). This indicates that gestational age and BMI, as included in the model, jointly provide a statistically significant contribution to explaining variation in neonatal Apgar scores.

Although the proportion of explained variance is moderate, the F-statistic indicates that the model fit is statistically robust. With 2 degrees of freedom for regression and 187 for residuals, the model demonstrates adequate explanatory performance.

Table 6. Multiple Linear Regression Coefficients

Variable	Standardized Interpretation		Confidence Interval B	t	p-value	VIF
	B	Std. Error	β			
Constant	-0.454	1.214		-0.374	0.709	
Body Mass Index (BMI)	-0.060	0.022	-0.167	-2.671	0.008	1.053
Gestational Age	0.223	0.028	0.494	7.913	<0.001	1.053

The multiple linear regression analysis demonstrated that both gestational age and body mass index (BMI) were significant predictors of neonatal Apgar score. BMI showed a significant negative association with Apgar score ($B = -0.060$; $\beta = -0.167$; $t = -2.671$; $p = 0.008$), indicating that higher maternal BMI is associated with lower neonatal Apgar scores. In contrast, gestational age showed a stronger positive association with Apgar score ($B = 0.223$; $\beta = 0.494$; $t = 7.913$; $p < 0.001$), indicating improved neonatal adaptation with increasing gestational age. The variance inflation factor ($VIF = 1.053$ for both variables) confirmed the absence of multicollinearity. Among the predictors, gestational age was the dominant determinant of neonatal Apgar score.

Based on the results of multiple linear regression analysis, the following equations were obtained: Apgar score = $-0.454 - 0.060(\text{BMI}) + 0.223(\text{Gestational Age})$

The equation indicates that the constant value of -0.454 represents the estimated Apgar score when both independent variables, body mass index (BMI) and gestational age, are equal to zero. Although this condition is not clinically plausible, it serves as a mathematical constant within the regression model.

The regression coefficient for BMI of -0.060 indicates that every 1 kg/m² increase in maternal BMI is associated with a 0.060-point decrease in neonatal Apgar score, assuming other variables remain constant. This finding suggests that higher or non-optimal BMI may contribute to poorer neonatal adaptation at birth. Meanwhile, the regression coefficient for gestational age of 0.223 indicates that each additional week of gestation is associated with a 0.223-point increase in Apgar score, assuming other variables remain constant. These results confirm that greater gestational maturity is associated with better neonatal adaptation at birth. Overall, the model demonstrates that gestational age has a more dominant positive effect compared to BMI, making it the main determinant of neonatal Apgar scores in this study. Maternal BMI, although statistically significant, contributes a smaller negative effect in the multivariate model.

Discussion

The median Apgar score observed in this study was 6.50 with an interquartile range of 3, indicating that neonatal adaptation during the early postnatal period was less than optimal for many newborns. A low Apgar score is widely recognized as a marker of compromised neonatal condition and has been associated with a range of adverse outcomes, including respiratory complications, neurological dysfunction, hypoxic injury, increased morbidity, and mortality shortly after birth (Cnattingius et al., 2020; Boos & Bühner, 2024). Consistent with these findings, recent epidemiological studies have reported that infants with lower 5-minute Apgar scores face elevated risks of admission to intensive care units, severe neonatal illnesses, and death during the neonatal period (Razaz et al., 2019; Ehrhardt et al., 2025).

The prognostic value of the Apgar score extends beyond the neonatal period. Several studies have demonstrated that low scores at birth may be linked to later neurodevelopmental problems, such as cerebral palsy and impaired cognitive functioning, particularly among high-risk infants (Kawakami et al., 2021). Despite its clinical usefulness, the Apgar score should be interpreted within the broader clinical context because neonatal condition at birth is determined by numerous interacting factors, including gestational maturity, prematurity status, and the adequacy of resuscitative interventions provided during labor and delivery (Stylianou-Riga et al., 2021).

The results of the bivariate analysis showed that gestational age had a significant positive correlation with Apgar score ($r = 0.549$; $p < 0.001$), indicating that higher gestational age is associated with better neonatal adaptation. Biologically, this can be explained by fetal organ maturation processes, particularly lung development, surfactant production, cardiovascular regulation, and neurological stability. Gestational age was the strongest determinant of neonatal Apgar score. This finding is biologically plausible as fetal organ maturity, particularly pulmonary and neurological systems, improves with advancing gestation, enhancing neonatal adaptation after birth (Sakunti et al., 2024). Previous studies also reported that preterm neonates have a higher risk of respiratory distress, adaptation disorders, and neonatal mortality compared to term neonates (Boos & Bühner, 2024). Large cohort studies have shown that each additional week of gestation contributes substantially to improved neonatal physiological stability and reduced risks of respiratory morbidity and low Apgar scores, particularly among late-preterm and early-term infants (Ehrhardt et al., 2025; Crump et al., 2019).

Furthermore, research by (Sumarni et al., 2023) confirmed that obstetric complications associated with preterm birth, such as placenta previa and premature rupture of membranes, significantly contribute to neonatal asphyxia. However, the magnitude of this association cannot be interpreted as a direct causal relationship due to the potential influence of unmeasured perinatal factors.

Conversely, maternal BMI showed a weak but significant negative correlation with Apgar score ($r = -0.329$; $p < 0.001$). In the multivariate analysis, BMI also remained significantly negative ($\beta = -0.167$; $p = 0.008$), although with a small effect size. These findings suggest that higher maternal BMI tends to be associated with lower neonatal Apgar scores. Clinically, this may be explained by the increased risk of maternal obesity, which is associated with gestational diabetes, preeclampsia, placental dysfunction, macrosomia, prolonged labor, and higher rates of cesarean delivery (Mitha et al., 2020); (Whelan et al., 2024). Recent evidence also indicates that maternal overweight and obesity are independently associated with lower neonatal Apgar scores and increased risks of birth asphyxia through inflammatory and metabolic mechanisms that affect placental function and fetal oxygenation (Weir et al., 2024; Razaz et al., 2023).

These conditions may impair uteroplacental perfusion and lead to reduced fetal oxygenation. Maternal BMI showed a weak but significant negative association with Apgar score. Obesity-related metabolic and obstetric complications, including impaired placental perfusion and prolonged labor, may contribute to reduced neonatal adaptation. Conversely, low BMI may reflect nutritional deficiency affecting fetal growth (Dubie et al., 2021). Previous studies also support that

maternal nutritional imbalance contributes to low birth weight, impaired fetal growth, and increased risk of neonatal asphyxia. (Sumarni, 2017) also emphasized that impaired maternal nutritional and hematological status can disrupt uteroplacental circulation, thereby affecting adverse neonatal outcomes. However, this relationship should be interpreted cautiously due to the presence of other contributing factors that were not fully assessed in this study.

Interestingly, hemoglobin levels and mean arterial pressure (MAP) did not show a significant association with Apgar scores. This may be explained by several factors. First, most respondents had hemoglobin and MAP values within a physiologically compensable range, resulting in limited variability and reduced statistical power. Second, single measurements of hemoglobin and blood pressure may not adequately reflect chronic oxygen transport status and uteroplacental perfusion during pregnancy. Maternal physiological adaptation, placental compliance, and antenatal interventions may mitigate the effects of mild anemia and moderate hemodynamic disturbances on neonatal outcomes (Young et al., 2023; Moore & Sinkey, 2023). Furthermore, the absence of a significant association in the present study may reflect compensatory placental and fetal adaptive mechanisms that help maintain oxygen delivery despite mild maternal hematological disturbances, thereby reducing their immediate impact on neonatal condition at birth (Zegarra et al., 2022; Smith et al., 2022).

The multivariable regression model explained 30.9% of the variance in neonatal Apgar scores, indicating that a substantial proportion of variability remains unexplained. This finding suggests that neonatal adaptation at birth is a complex and multifactorial process influenced by numerous maternal, fetal, intrapartum, and neonatal factors beyond those included in the present study. Variables such as birth weight, fetal sex, mode of delivery, duration of labor, intrapartum fetal distress, neonatal resuscitation practices, maternal comorbidities, placental abnormalities, and socioeconomic factors have been reported to contribute significantly to neonatal outcomes and may account for additional variation in Apgar scores (Stylianou-Riga et al., 2021; Whelan et al., 2024). Consequently, while gestational age and maternal BMI emerged as significant predictors in this study, the relatively modest explanatory power of the model indicates that these factors represent only part of the determinants of neonatal condition at birth.

This limitation should be considered when interpreting the findings. The observed associations do not imply that gestational age and maternal BMI are the sole determinants of neonatal Apgar scores. Future studies should incorporate a broader range of maternal, fetal, placental, and intrapartum variables and consider prospective study designs to better capture the complex pathways influencing neonatal adaptation and improve the predictive performance of statistical models.

Furthermore, the effects of hemoglobin and MAP on neonatal outcomes are likely indirect and mediated by factors such as placental perfusion, inflammatory status, oxidative stress, and obstetric complications that were not measured in this study. Therefore, although these variables are physiologically important in fetal oxygenation, the findings of this study suggest that their direct contribution to Apgar scores is not statistically significant within this model.

Research Contribution

This study highlights gestational age as the primary determinant of neonatal Apgar score, with maternal BMI contributing modestly, while hemoglobin and MAP show no independent effect. The findings support integrated antenatal monitoring focusing on fetal maturity and maternal nutrition.

Study Limitations

A limitation of this study is that the final regression model accounted for only 30.9% of the variation in neonatal Apgar scores. This suggests that other important determinants of neonatal outcomes were not captured in the available dataset. Factors such as birth weight, mode of delivery, fetal distress, neonatal resuscitation, maternal comorbidities, and placental characteristics were not

included and may have contributed to the unexplained variance. Therefore, the findings should be interpreted within the context of these unmeasured factors.

Recommendations

This study recommends strengthening comprehensive antenatal care with emphasis on gestational age and maternal nutritional status as key indicators of neonatal adaptation risk. Early screening should be prioritized to detect pregnancies at risk of low Apgar scores, particularly in mothers with abnormal BMI. Future research is encouraged to include additional confounding factors such as mode of delivery, intrapartum conditions, and placental factors to improve predictive accuracy. Longitudinal or cohort designs are also recommended to strengthen causal inference regarding determinants of neonatal Apgar scores.

CONCLUSION

Gestational age showed the strongest association with neonatal Apgar score, followed by maternal BMI, while hemoglobin and MAP were not significantly associated with the outcome. These findings suggest a potential role of fetal maturity and maternal nutritional status in neonatal adaptation. However, neonatal outcomes are multifactorial, and additional unmeasured factors may contribute to variations in Apgar scores.

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AUTHOR CONTRIBUTION STATEMENT

SS led the study conception, data acquisition, statistical evaluation, and manuscript preparation. DP was involved in designing the research methodology, guiding the data analysis, interpreting the study findings, and critically reviewing the manuscript for important intellectual content. All authors read, revised, and approved the final manuscript prior to submission.

AI DISCLOSURE STATEMENT

This manuscript uses ChatGPT (OpenAI) to structure the text and correct grammar. All content has been reviewed and validated by the authors.

CONFLICTS OF INTERES

The author declares that there is no conflict of interest, whether financial, institutional, or personal, that could influence the implementation of the research, data analysis, manuscript preparation, or publication process of this article.

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