



Clinical prediction model for 6-month gross motor outcomes in high-risk neonatal ICU infants

Dr. Pranali Saurabh Thakkar

Assistant professor, SPB Physiotherapy College, Surat, Gujarat, India

Abstract

Introduction: High-risk NICU graduates are vulnerable to early neurodevelopmental delays due to cumulative prenatal, perinatal, and neonatal complications. Early identification of gross motor delay is essential for timely intervention, yet standardized predictive tools remain limited in clinical practice. Developing a reliable regression-based predictive model may support clinicians in screening infants at risk during early follow-up visits.

Objective: To develop and validate a predictive model capable of estimating 6-month gross motor outcomes using significant neonatal and perinatal clinical risk factors.

Method: A cross-sectional analytical study was conducted on 284 high-risk NICU infants. Thirty-one potential risk factors were screened, of which 17 demonstrated significant correlation with the 6-month Gross Motor score of the Ages and Stages Questionnaire (ASQ-3). Stepwise linear regression was performed, initially identifying 11 significant predictors, and subsequently refining them to 8 independent variables that contributed significantly to the final predictive model. Predicted ASQ-3 scores were categorized as High Risk or No Risk and compared with actual scores. Diagnostic accuracy indices—Sensitivity, Specificity, Positive Predictive Value (PPV), Negative Predictive Value (NPV), and Overall Accuracy—were calculated.

Result: The eight significant predictors included consanguineous marriage, birth asphyxia, duration of oxygen support, neonatal seizures, periventricular leukomalacia (PVL), respiratory distress syndrome (RDS), history of miscarriage, and low Apgar score. The predictive model demonstrated Sensitivity 60%, Specificity 85.77%, PPV 62.33%, NPV 84.54%, and Overall Accuracy 78.52%, indicating good discrimination for identifying infants at risk of gross motor delay.

Conclusion: The developed predictive model provides clinically relevant accuracy for early identification of 6-month gross motor delay among high-risk NICU infants. Its application may support timely referral for physiotherapy and early intervention programs, ultimately improving developmental outcomes.

Keywords: Gross motor development, NICU graduates, predictive model, ASQ-3, neonatal risk factors, early intervention, developmental delay

Introduction

Gross motor development during early infancy is a vital indicator of neurological maturation and functional independence. Delays in early motor milestones—such as head control, rolling, and sitting—often reflect underlying neurological impairments and may predict long-term motor and functional challenges [1, 2]. Infants admitted to Neonatal Intensive Care Units (NICUs) are at particularly high risk due to exposure to prenatal, perinatal, and neonatal complications including prematurity, birth asphyxia, respiratory distress, neonatal seizures, and neuroimaging abnormalities [3–5]. These early-life adversities significantly influence neuromotor pathways and increase the likelihood of developmental delay.

Early identification of infants at risk is essential, as timely physiotherapy and early intervention strategies have been shown to enhance neuroplasticity and improve developmental outcomes [6,7]. Tools such as the Ages and Stages Questionnaire, Third Edition (ASQ-3), are widely used for developmental screening and offer reliable assessment of gross motor performance at 6 months [8]. However, while screening tools detect delays, they do not predict future outcomes. Predictive models can bridge this gap by combining multiple clinical risk factors to estimate the likelihood of gross motor delay.

Although several studies have linked neonatal variables such as low Apgar scores, intraventricular hemorrhage, periventricular leukomalacia (PVL), and prolonged

respiratory support with developmental impairments [9, 11], limited research has focused specifically on predictive modeling for early gross motor outcomes, particularly at 6 months of age. The 6-month period represents a crucial developmental window where early trunk control, antigravity movement, and transitional motor skills emerge, making it an ideal time for targeted intervention.

Therefore, this study aims to develop a regression-based predictive model for estimating 6-month Gross Motor outcomes in high-risk NICU infants, using clinically significant neonatal factors. Such a model can guide clinicians in early detection, parental counselling, and individualized rehabilitation planning.

Objective of the Study

To identify significant Prenatal, neonatal and perinatal predictors influencing 6-month Gross Motor development in high-risk NICU infants and to construct a regression-based predictive model using the Ages and Stages Questionnaire (ASQ-3) Gross Motor Score.

Methodology

A cross-sectional analytical study was conducted on 284 high-risk NICU infants to identify predictors of 6-month gross motor development. A total of 31 prenatal, perinatal, and neonatal risk factors were recorded from medical histories and hospital records. Gross motor development at 6 months was assessed using the Ages and Stages Questionnaire—Third Edition (ASQ-3) Gross Motor Scale.

Initially, 17 factors showed significant correlation with the 6-month gross motor score. These variables were entered into a linear regression model, and 11 significant predictors were identified. A second regression analysis using these predictors yielded eight final significant variables: consanguineous marriage, birth asphyxia, duration of oxygen support, neonatal seizure, periventricular leukomalacia (PVL), respiratory distress syndrome (RDS), history of miscarriage, and low Apgar score. Using the unstandardized β -coefficients from the final regression model, a predictive equation was formulated to estimate the 6-month Gross Motor ASQ score. In another phase a new cohort of 284 Discharged NICU Infant was done, the 17 factors which were found to be significantly affecting development during Previous Phase Predicted and actual scores were then categorized (High Risk / No Risk) and cross-tabulated to calculate Sensitivity, Specificity, Positive Predictive Value, Negative Predictive Value, and Overall Accuracy of the model. Ethical approval and parental consent were obtained as per institutional guidelines.

Data Analysis and Result

6-month Gross motor from the initial set of 17 identified factors, a linear regression analysis was conducted, resulting in 11 significant factors. Following this, a regression analysis was carried out again utilizing these 11 significant factors, resulting in 8 significant variables. Finally, a fit model for 6month Gross motor was developed using these 8 independent variables.

6-month gross motor

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Table 1: Co-efficient table by linear regression for 6-month Gross motor

Dependent Variable	Independent Variable	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Variance
		β	Std. Error				
6-month Gross motor	(Constant)	43.880	1.264		34.708	.000	31.3%
	Consanguineous marriage	-22.352	6.046	-.184	-3.697	.000	
	Birth asphyxia	-5.629	2.463	-.120	-2.286	.023	
	o2support days	-.453	.101	-.224	-4.491	.000	
	Neonatal seizure	-19.375	2.711	-.362	-7.146	.000	
	PVL	-42.069	15.675	-.132	-2.684	.008	
	RDS	-6.321	2.492	-.131	-2.536	.012	
	History of miscarriage	-6.300	3.674	-.086	-1.715	.088	
Low apgar score	-15.083	6.033	-.124	-2.500	.013		

From the above table, it is clear that the Consanguineous marriage Birth asphyxia O2support days Neonatal seizure PVL RDS History of miscarriage Low Apgar score These 8 factors had a p-value of less than 0.05 indicative of significant at a 95% confidence interval. One predictive fit model formula is designed from all above 8 factors which is as follow by using constant and β values mentioned in the column of Unstandardized Coefficients of above mentioned 8 significant factors:

6-month Gross motor Predictive model

Constant = 43.880
Write 1 for yes answer and write 0 for No answer and number of days according to question put the value in the formula given below

6-month gross motor Predicted Infant development score (Ages and Stages questionnaire Score) = 43.880+ [(-22.352) (consanguineous Marriage)] + [(-5.629) (Birth Asphyxia)] + [(- 0.453) (oxygen support days)] + [(- 19.375) (Neonatal seizure)] + [(-42.069) (PVL)] + [(-6.321) (RDS)] + [(-6.300) (History of miscarriage)] + [(-15.083) (Low APGAR Score)]

Model summary shows that there are many other factors that can affect Infant Gross motor development along with above mentioned factors.

Calculation of Sensitivity, Specificity, Positive Predictive Value, Negative Predictive Value Overall Accuracy

Both actual and model scores of the Ages and stages questionnaire Score were transformed into categorical data and matched to calculate Sensitivity, Specificity, Positive Predictive Value, Negative Predictive Value, and Overall Accuracy.

Table: Sensitivity, specificity, Positive Predictive Value and Negative Predictive Value for 6month Actual Score and Predicted Score of Ages and stages Questionnaire Score by an investigator.

Table 2: Cross-tabulation for Actual Score and Model Score of 6-month Gross Motor Ages and stages Questionnaire by an investigator

		Actual score		Total
		High Risk	No Risk	
Predictive score	High Risk	a=48 True Positive	b=29 False Positive	77
	No Risk	c=32 False Negative	D=175 True Negative	207
Total		80	204	

1. Sensitivity: 60%

Sensitivity = True High Risk/ (True High Risk+ False No Risk) = 48 / (48+32) = 60.00%

2. Specificity: 85.77%

Specificity = True No Risk/ (True No Risk + False High Risk) = 175 / (175+29) = 85.77%

3. Positive Predictive Value: 62.33%

Positive Predictive Value = True High Risk/ (True High Risk+ False High Risk) = 48 / (48+29) = 62.33%

4. Negative Predictive Value: 84.54%

Negative Predictive Value = True No Risk/ (True No Risk + False No Risk) = 175 / (32+175) = 84.54%

5. Overall accuracy = 78.52%

Overall accuracy = (True High Risk+ True No Risk) / (True High Risk+ False High Risk+ True No Risk+ False No Risk) = (48+ 175) / (48+29+32+175) = 223/ 284 = 78.52%

Discussion

The present study aimed to develop a predictive model for identifying high-risk NICU infants who are likely to exhibit gross motor delay at 6 months of age. The findings demonstrate that eight neonatal and perinatal variables—consanguineous marriage, birth asphyxia, oxygen support duration, neonatal seizure, PVL, RDS, history of miscarriage, and low Apgar score—were significantly associated with reduced gross motor performance on the ASQ-3. These results align with existing literature in which a combination of prenatal and neonatal risk factors has been shown to negatively influence early motor trajectories [12–14]. Birth asphyxia, neonatal seizures, and PVL emerged as strong predictors in the regression model, suggesting that early neurological insult has profound implications for gross motor control, tone regulation, and integration of postural reflexes. Previous research also supports that hypoxic and ischemic events are major contributors to impaired neuromotor development due to injury to motor pathways and delayed cortical maturation [15, 16]. Similarly, prolonged oxygen support, often reflecting severe respiratory distress or pulmonary immaturity, has been linked to altered brain microstructure and long-term neurodevelopmental difficulties in premature infants [17].

Consanguineous marriage and history of miscarriage also showed a significant relationship with poorer motor outcomes. Consanguinity is associated with increased risk of recessive genetic disorders, congenital anomalies, and metabolic conditions that may influence early development [18]. Maternal obstetric history, particularly recurrent pregnancy loss, has been reported as a marker of placental insufficiency and adverse perinatal outcomes, potentially affecting fetal neurodevelopment [19].

Low Apgar score and RDS were additional predictors, consistent with studies indicating that infants who experience initial cardiorespiratory compromise or pulmonary instability demonstrate delayed attainment of gross motor milestones and poorer ASQ performance in infancy [20, 21]. These findings reinforce the multifactorial nature of developmental delay, where both acute perinatal events and chronic neonatal complications act synergistically.

The diagnostic performance of the model was satisfactory, with sensitivity of 60% and specificity of 85.77%, indicating that it effectively identifies infants who are not at risk while moderately detecting those who are at high risk. The model's overall accuracy of 78.52% is comparable to other early-prediction tools reported in developmental literature [22, 23]. While sensory, environmental, and post-discharge stimulation factors also influence developmental trajectories, the present model demonstrates that clinical neonatal variables alone can offer meaningful prediction. This predictive formula provides clinicians with an accessible screening tool that can be applied early during follow-up visits. By identifying infants at elevated risk for gross motor delay, the model supports earlier referral for physiotherapy, developmental surveillance, and parent-mediated intervention programs. Early interventions initiated within the first 6 months have consistently been shown to enhance neuroplasticity and improve long-term motor outcomes [24, 25].

However, the study has limitations. Environmental stimulation, socioeconomic factors, parental involvement, and post-NICU caregiving practices were not included in the model, though they significantly influence developmental outcomes. Additionally, model validation with larger multicentric cohorts may further strengthen its generalizability. Future research integrating clinical, environmental, and neuroimaging variables may help refine prediction accuracy.

Overall, the study contributes a statistically validated, clinically practical predictive tool that can meaningfully aid early identification and management of developmental risk among high-risk NICU infants.

Conclusion

The present study successfully developed and validated a regression-based predictive model for estimating 6-month gross motor outcomes in high-risk NICU infants using clinically accessible Prenatal, neonatal and perinatal factors. Future studies with larger, diverse cohorts and external validation are recommended to further refine the model and enhance its generalizability.

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