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ORIGINAL RESEARCH

Development and Validation of a Nosocomial Infection Nomogram Model in the NICU: A Novel and Nurse-Led Way to Prediction in Preterm Infants

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Purpose: Nosocomial infections (NI) are a leading cause of mortality in preterm infants in the Neonatal Intensive Care Unit (NICU). The key to reducing the risk of NI is early detection and treatment in time. Nurses are close observers and primary caregivers for neonates at the bedside of the NICU, who are best positioned to capture the risk signals of NI. This study aims to develop a nurse-led prediction model for NI of preterm infants in the NICU.

Patients and Methods: This study was designed as a retrospective study, preterm infants of the NICU at Renmin Hospital of Wuhan University from January 2020 to December 2023 were selected and divided into the NI group and non-NI group. Clinical data were collected and then analyzed by univariate analysis, least absolute shrinkage and selection operator (LASSO) regression analysis, and multivariate logistic regression analysis. The outcome constructed a nomogram model and its predictive efficacy was evaluated by the area under the receiver operating characteristic curve (AUC), calibration curve, and decision curve analysis (DCA). Bootstrap method was used to repeat 1,000 times for internal validation.

Results: A total of 892 preterm infants were finally included and a nurse-led predictive model established, which included six variables: skin color changes, respiratory related changes, feeding deterioration, birth weight, number of arterial and venous blood draws, and days of nasogastric tube placement. The model's AUC was 0.953, indicating good discriminatory power. The calibration plot demonstrated good calibration and the Hosmer–Lemeshow test showed high consistency. DCA indicated that the nomogram had good clinical utility. Internal validation showed the AUC of 0.952.

Conclusion: This nomogram model, which is mainly based on nurses' observations, shows good predictive ability. It offered a more convenient option for neonatologists and nurses in the NICU.

Keywords: nosocomial infection, preterm infants, prediction model, nomogram, nurse-led

Introduction

Nosocomial infections (NI), also known as hospital-acquired infections (HAIs), are infections that are acquired during a patient's stay in a healthcare facility. NI is a leading cause of mortality of neonates, especially preterm infants in the Neonatal Intensive Care Unit (NICU) who are at high risk for various infections, including respiratory system infection, necrotizing enterocolitis, urinary tract infection and other infectious diseases.[1,2] A meta-analysis study showed that the incidence of NI was as high as 26.3%, and another study indicated that 19.9% of preterm infants had at least one kind of NI.[3,4] Given that neonates are immunocompromised, NI can easily result in severe complications or even death if unrecognized and untreated in time. It also leads to extended hospital stays and hospitalization costs.[5]

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The key to mitigating adverse outcomes following NI is early detection and prompt treatment. Critical neonatal care emphasizes the importance of direct observation and comprehensive analysis by physicians and nurses at the bedside. NICU nurses play a crucial role as 24-hour bedside guardians, providing continuous observation, intuitive data collection, dynamic evaluation and timely feedback on changes in newborns' conditions, which assists doctors in formulating treatment plans. Moreover, by leveraging constant monitoring, nurses can better detect early signs of NI in preterm infants. Therefore, nurses play a unique role in early detection of NI in premature infants.

Currently, the increasing clinical use of disease prediction models is beneficial for predicting disease occurrence through the analysis of early indicators. Neonatal NI is the same, but most of the models are clinician-led and typically focus on laboratory indicators such as blood culture result, complete blood count, and indicators of infection.[6–8] In the NICU, compared to neonatologists, nurses spend the most time with patients and are the first to know and most familiar with changes in their clinical manifestations. Therefore, developing a prediction model for NI, mainly based on nurses' real-time observation and early clinical data, is a meaningful and innovative effort.

Materials and Methods

Definition and Population

According to the definition of the United States Centers for Disease Control and Prevention (CDC) and China CDC, clinical manifestations of infection and positive culture from the site of infection at or after 48 hours post-birth were considered to be horizontal transmission of infection. In our study, In our study, infections that were clinically diagnosed by doctors in the medical records and occurred more than 48 hours after admission to the NICU were considered to be NI, excluding prenatal or intrapartum infections.[9,10]

This study included all premature infants hospitalized in the NICU of Renmin Hospital of Wuhan University between January 2020 and December 2023 (48 months). It is a tertiary medical institution with a Level III C NICU. Inclusion criteria were as follows: (1) patients whose gestational age >26 weeks and <37 weeks; (2) patients whose length of stay in the NICU was ≥48h. Exclusion criteria included any of the following: (1) patients with pre-existing diseases, natural malformations or genetic metabolic diseases; (2) patients with prenatal or intrapartum infections; (3) patients with incomplete clinical data.

This study was reported following the Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis (TRIPOD) guidelines, complied with the Declaration of Helsinki and was approved by the Medical Ethics Committee (approval number: WDRY2023-K098) at Renmin Hospital of Wuhan University. According to Article 39 of the "Ethical Review Measures for Biomedical Research Involving Humans" issued by the National Health and Family Planning Commission of China, the following circumstances may be exempted from the requirement for signed informed consent upon approval by the ethics committee: research utilizing human materials or data with identifiable identity information, where the subjects could no longer be located, and the research project did not involve personal privacy or commercial interests. Since this study was a retrospective analysis, all patients were de-identified prior to the research, and verbal informed consent was obtained from their relatives.

Data Collection

Based on literature review, expert consultation and previous research, our study was designed to collect the data by integrating the possible influencing factors of NI of premature neonates hospitalized in NICU. The data mainly contains the following 5 categories: (1) Baseline data: including gender, gestational age, and birth weight. (2) Perinatal histories: assisted reproductive technology, premature rupture of membranes, and cesarean section, 1-min Apgar score, 5-min Apgar score. (3) Clinical observations and events within 0–5 days (120h) before diagnosis of NI: respiratory indicators (raised respiratory rate: 60 breaths per minute or more, grunting, apnea, oxygen saturation of less than 90% in air or increased oxygen, requirement over baseline); skin indicators (has a change in skin colour, for example, when the baby becomes very pale, blue/gray or dark yellow, mottled or ashen appearance, cyanosis of skin, lips or tongue, on-blanching rash of skin); feeding difficulties (for example, feed refusal); feeding intolerance, including vomiting, excessive gastric aspirates and abdominal distension; feeding deterioration (alterations in feeding pattern, has developed new difficulties

with feeding). (4) Invasive procedures: peripherally inserted central catheter (PICC), days of peripherally inserted central catheter placement (PICC days), days of nasogastric tube placement (NGT days), number of arterial and venous blood draws, days of parenteral nutrition (PN days).

Statistical Analysis

Statistical analysis was conducted using G*Power software version 3.1.9.7 first to estimate the power of their sample size, then using R software version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria) and SPSS version 25.0 (SPSS, Chicago, IL, the United States) for the following statistics. Continuous variables were analyzed using T-tests for those with a normal distribution or Wilcoxon rank-sum tests for those without normal distribution. For categorical variables, X2 or Fisher's exact test was used. The findings were reported as means ± standard deviations for normally distributed variables, medians with the 25th and 75th percentiles for non-normally distributed variables, and cases and percentages for categorical data.

All the included variables ($P < 0.05$) after univariate analysis ($P < 0.05$) were entered into lasso regression analysis. Then, the best penalty term coefficient λ was determined by 3-fold cross-validation and those variables that screened out were entered into multivariate logistic regression analysis. Finally, variables ($P < 0.05$) after it was chosen to establish a predictive model.

The "rms" package of R software (https://CRAN.R-project.org/package=rms) was used to analyze and draw a nomogram to represent this model. The discrimination of the model was assessed using the receiver operating characteristic (ROC) curve. Bootstrap method was used to repeat 1,000 times for internal validation. H-L goodness-of-fit test and calibration curve were used to evaluate and calibrate the nomogram model. Drawing the decision curve to evaluate the clinical efficacy of the nomogram model.

Results

Baseline and Characteristics of Population

The study examined the medical records of 2670 newborns admitted to the NICU of Renmin Hospital of Wuhan University from January 2020 to December 2023. Of these, 1778 neonates were excluded for not fulfilling the inclusion criteria or for the exclusion criteria. Finally, 168 preterm infants with NI and 724 controls were identified as study subjects. Figure 1 illustrates the flowchart of the research steps.

Baseline data comparing NI and non-NI preterm infants are shown in Table 1. Among all the variables, only 5-min Apgar score had a small number of 19 missing data, with a missing ratio of 2.13%. According to the distribution of this variable, the median value was used to fill in the missing data. There were 390 (43.72%) females and 502 (56.28%) males. Of all the participants, 168 (18.8%) had NI. Results of univariate logistic regression analysis showed that 14 variables, including the gestational age, birth weight, 1-min Apgar score, 5-min Apgar score, days of nasogastric tube placement, number of arterial and venous blood draws, days of parenteral nutrition, PICC days, whether cesarean section, whether they have nasogastric tube placement, respiratory related changes, skin color changes, feeding intolerance, feeding deterioration of two groups were statistically significant ($P < 0.05$).

Lasso Regression Analysis and Multivariate Logistic Regression Analysis

The variables selected in the previous step were entered into Lasso regression analysis for further narrowing down the scope. The best penalty term coefficient λ was determined by 3-fold cross-validation of the LASSO regression model, and 9 potential influencing factors were finally screened out. They were gestational age, birth weight, days of nasogastric tube placement, number of arterial and venous blood draws, days of parenteral nutrition, respiratory related changes, skin color changes, feeding intolerance, and feeding deterioration, as shown in Figure 2A and B.

Afterwards, the 9 potential influencing factors mentioned above were included in a multivariate logistic regression analysis. The results shown in Table 2 indicated that birth weight, number of arterial and venous blood draws, days of nasogastric tube placement, respiratory related changes, skin color changes, and feeding deterioration were the risk factors for NI in premature infants.

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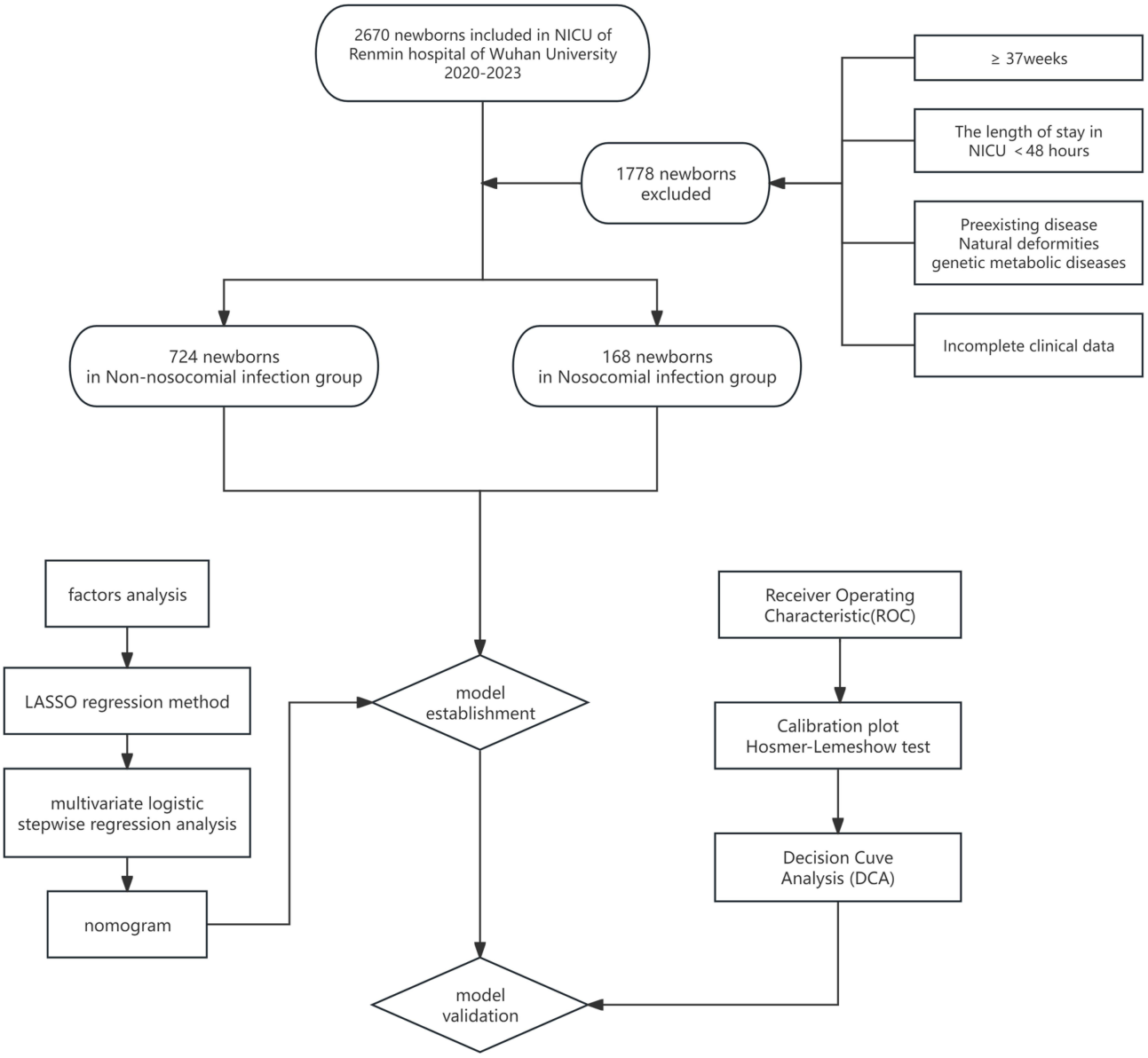

Figure 1 Flowchart of the study.

Development and Validation of a Nomogram Model for NI

Based on the above 6 factors, a nomogram model was constructed to predict the risk of NI in preterm infants in the NICU, as shown in Figure 3A. Using the nomogram, a vertical line was drawn upward from each variable to the top scoring line, and the corresponding scores were obtained. Then, the scores corresponding to each variable were summed to determine the total score. Finally, the predicted probability of NI in preterm infants corresponding to the bottom of the nomograph was obtained based on the total score.

To evaluate the effectiveness of this predictive model, several key indicators were monitored and analyzed. First, the discrimination capacity of the nomogram was assessed using the Area Under the Curve (AUC) and the AUC value of it was 0.953, indicating a high accuracy compared with the other six independent risk factors shown in Figure 3B. The AUCs of birth weight, days of nasogastric tube placement, number of arterial and venous blood draws, respiratory related changes, skin color changes, and feeding deterioration were 0.799, 0.798, 0.722, 0.784, 0.691 and 0.667, respectively.

Table 1 Characteristics Between Non-Nosocomial Infection and Nosocomial Infection Patients

Variables	Total (n = 892)	Non-Nosocomial Infection (n = 724)	Nosocomial Infection (n = 168)	Statistic	*P*
GA (week), M (Q_1, Q_3)	34.14 (32.29, 35.29)	34.43 (33.14, 35.43)	31.71 (29.71, 33.61)	Z=−11.62	**<0.001**
Weight (kg), M (Q_1, Q_3)	2.04 (1.71, 2.37)	2.13 (1.82, 2.43)	1.62 (1.21, 1.90)	Z=−12.08	**<0.001**
APGAR-1min, M (Q_1, Q_3)	8.00 (8.00, 9.00)	8.00 (8.00, 9.00)	8.00 (7.00, 8.00)	Z=−6.08	**<0.001**
APGAR-5min, M (Q_1, Q_3)	9.00 (9.00, 9.00)	9.00 (9.00, 9.00)	9.00 (8.00, 9.00)	Z=−4.99	**<0.001**
NGT days, M (Q_1, Q_3)	0.00 (0.00, 5.00)	0.00 (0.00, 1.00)	5.00 (4.00, 5.00)	Z=−14.13	**<0.001**
ABG/VBG draws, M (Q_1, Q_3)	2.00 (1.00, 2.00)	2.00 (1.00, 2.00)	2.00 (2.00, 3.00)	Z=−9.57	**<0.001**
PN days, M (Q_1, Q_3)	4.00 (1.00, 5.00)	3.00 (0.00, 5.00)	5.00 (5.00, 5.00)	Z=−11.28	**<0.001**
PICC days, M (Q_1, Q_3)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	Z=−4.62	**<0.001**
Gender, n(%)				χ^2=0.18	0.672
Female	390 (43.72)	319 (44.06)	71 (42.26)		
Male	502 (56.28)	405 (55.94)	97 (57.74)		
Cesarean Section, n(%)				χ^2=11.68	**<0.001**
N	194 (21.75)	141 (19.48)	53 (31.55)		
Y	698 (78.25)	583 (80.52)	115 (68.45)		
PROM, n(%)				χ^2=2.13	0.144
N	650 (72.87)	520 (71.82)	130 (77.38)		
Y	242 (27.13)	204 (28.18)	38 (22.62)		
ART, n(%)				χ^2=0.08	0.773
N	545 (61.10)	444 (61.33)	101 (60.12)		
Y	347 (38.90)	280 (38.67)	67 (39.88)		
NGT, n(%)				χ^2=173.77	**<0.001**
N	564 (63.23)	532 (73.48)	32 (19.05)		
Y	328 (36.77)	192 (26.52)	136 (80.95)		
PICC, n(%)				χ^2=0.00	1.000
N	866 (97.09)	703 (97.10)	163 (97.02)		
Y	26 (2.91)	21 (2.90)	5 (2.98)		
Respiratory Changes, n(%)				χ^2=381.86	**<0.001**
N	773 (86.66)	705 (97.38)	68 (40.48)		
Y	119 (13.34)	19 (2.62)	100 (59.52)		
Skin Color Changes, n(%)				χ^2=283.68	**<0.001**
N	824 (92.38)	721 (99.59)	103 (61.31)		
Y	68 (7.62)	3 (0.41)	65 (38.69)		
Feeding Intolerance, n(%)				χ^2=172.19	**<0.001**
N	807 (90.47)	700 (96.69)	107 (63.69)		
Y	85 (9.53)	24 (3.31)	61 (36.31)		
Feeding Deterioration, n(%)				χ^2=208.40	**<0.001**
N	821 (92.04)	712 (98.34)	109 (64.88)		
Y	71 (7.96)	12 (1.66)	59 (35.12)		

Notes: The bold text in the p-value column indicates statistically significant results ($p < 0.05$).

Abbreviations: M, Median; Q_1, 1st Quartile, Q_3, 3st Quartile; Z, Mann–Whitney test; χ^2, Chi-square test; GA, gestational age; NGT days, days of nasogastric tube placement; ABG/VBG draws, number of arterial and venous blood draws; PN days, days of parenteral nutrition; PICC days, days of peripherally inserted central catheter placement; PROM, premature rupture of membranes; ART, assisted reproductive technology;NGT, nasogastric tube placement.

Second, the calibration plot was employed to assess the alignment between the actual probability and predicted probability of NI in preterm infants, which showed good fitness with a p-value of 0.687 for the Hosmer–Lemeshow test, shown in Figure 4A. Finally, internal validation by bootstrap analysis based on 1000 Bootstrap samples was performed and results ranged from 0.933 to 0.970 of AUC and average value was 0.952, shown in Figure 4B.

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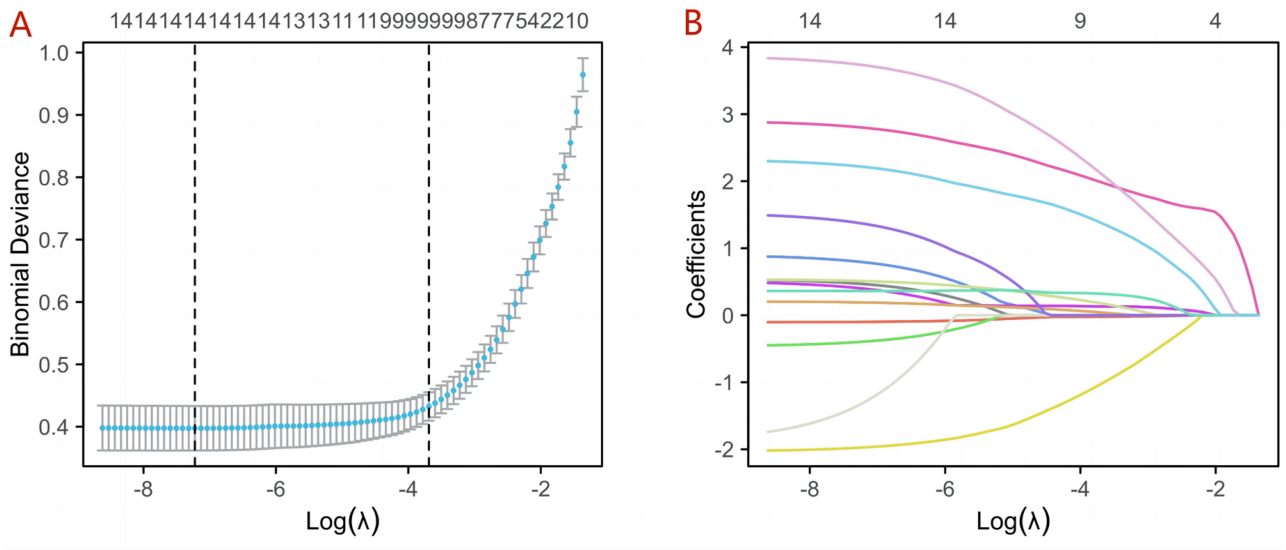

Figure 2 Feature selection by using LASSO regression method. (**A**) Cross validation plot. (**B**) Regularization path of LASSO coefficient.

Furthermore, following an evaluation of the performance of the nomogram model, DCA was also conducted to confirm the predictive effectiveness of the nomogram. The results indicated that the net benefit of the nomogram model was greater than 0 over a wide range of threshold probabilities (Figure 5), suggesting that the superior clinical utility of the nomogram in the present study was generalizable.

All of the above results demonstrate the excellent predictive performance and high accuracy of the model.

Table 2 Multivariate Analysis of Variables by Logistic Regression Analysis

Variables	Total	Multivariate Analysis	
		Odds Ratio (95% CI)	*P*
GA	892	0.98 (0.81–1.18)	0.827
Weight	892	0.14 (0.05–0.36)	**< 0.001**
NGT days	892	1.17 (1.02–1.34)	**0.030**
ABG/VBG draws	892	1.54 (1.21–1.98)	**< 0.001**
PN days	892	1.18 (0.98–1.42)	0.075
Respiratory Changes	892		
N	773	Reference	
Y	119	13.69 (6.54–28.64)	**< 0.001**
Skin Color Changes	892		
N	824	Reference	
Y	68	39.72 (9.88–159.74)	**< 0.001**
Feeding Intolerance	892		
N	807	Reference	
Y	85	1.38 (0.57–3.36)	0.479
Feeding Deterioration	892		
N	821	Reference	
Y	71	7.76 (2.93–20.53)	**< 0.001**

Notes: The bold text in the p-value column indicates statistically significant results ($p < 0.05$).

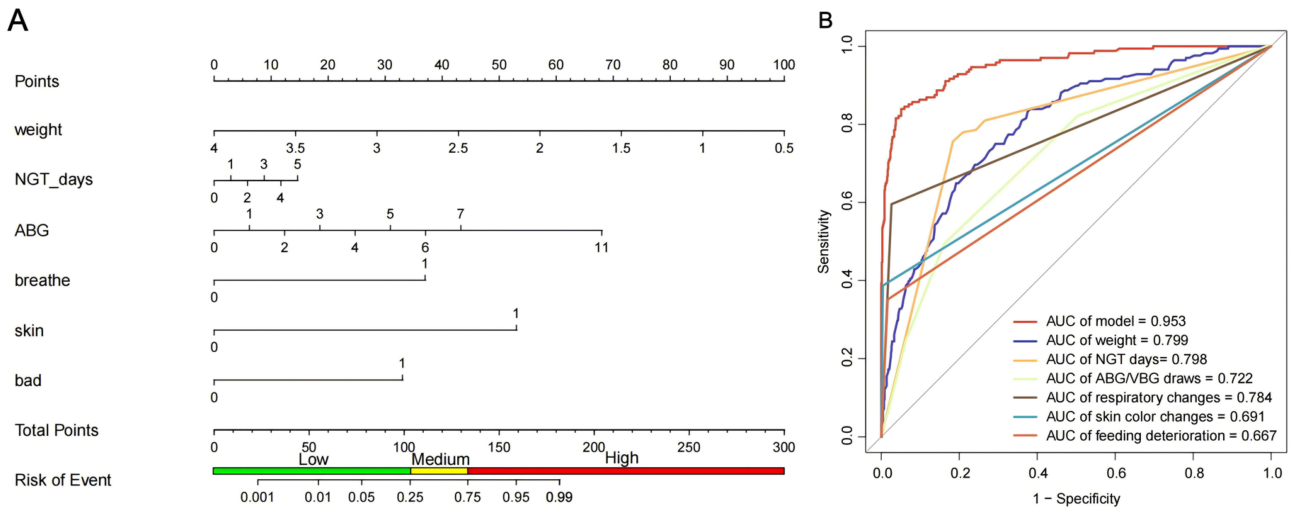

Figure 3 Nomogram, ROC and AUC of predictive model. (**A**) Nomogram of predictive model for nosocomial infection. (**B**) ROC and AUC of predictive model and signal indicator.

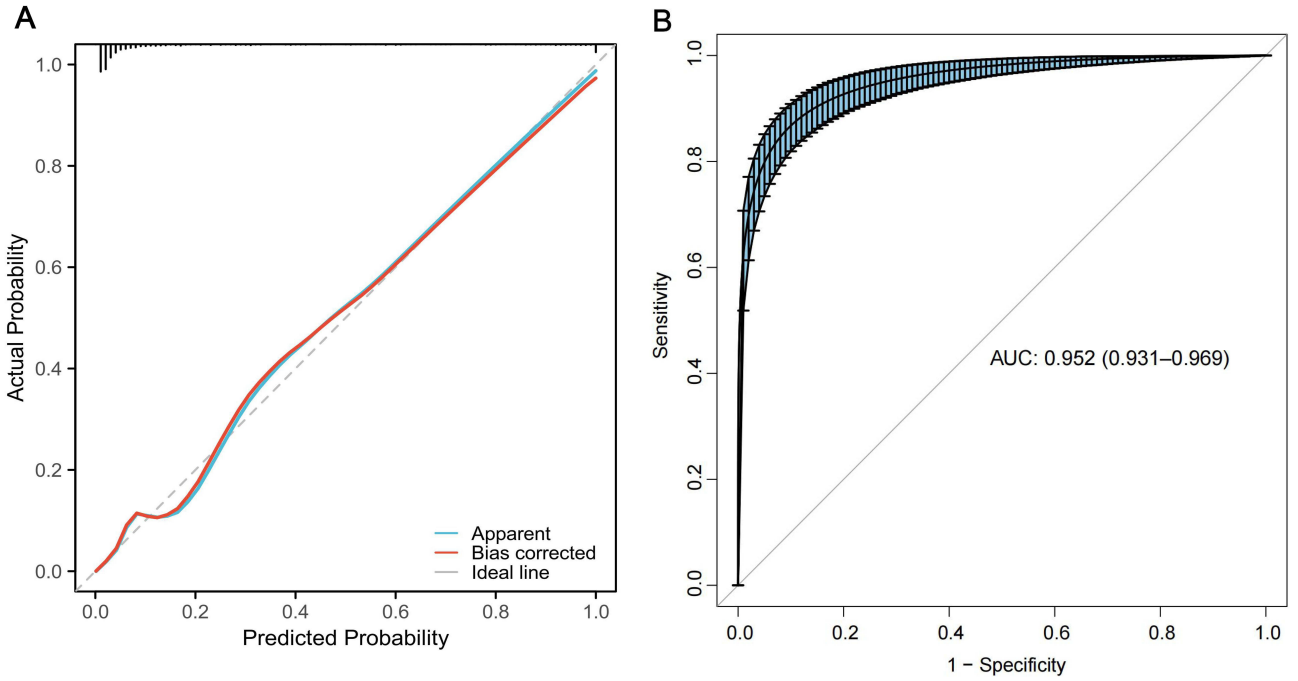

Figure 4 Calibration plot and internal validation of predictive model. (**A**) The calibration plot represents the predicted probability of nosocomial infection; (**B**) Bootstrap resampling of 1000 replications for internal validity.

Discussion

Newborns, due to their special age group, are a key population for monitoring NI. Among them, preterm infants, who have smaller gestational ages, lower birth weights and less mature organ development, are at an even higher risk of NI. Overall, early prevention, early identification and timely treatment are still significant challenges in NICU management.

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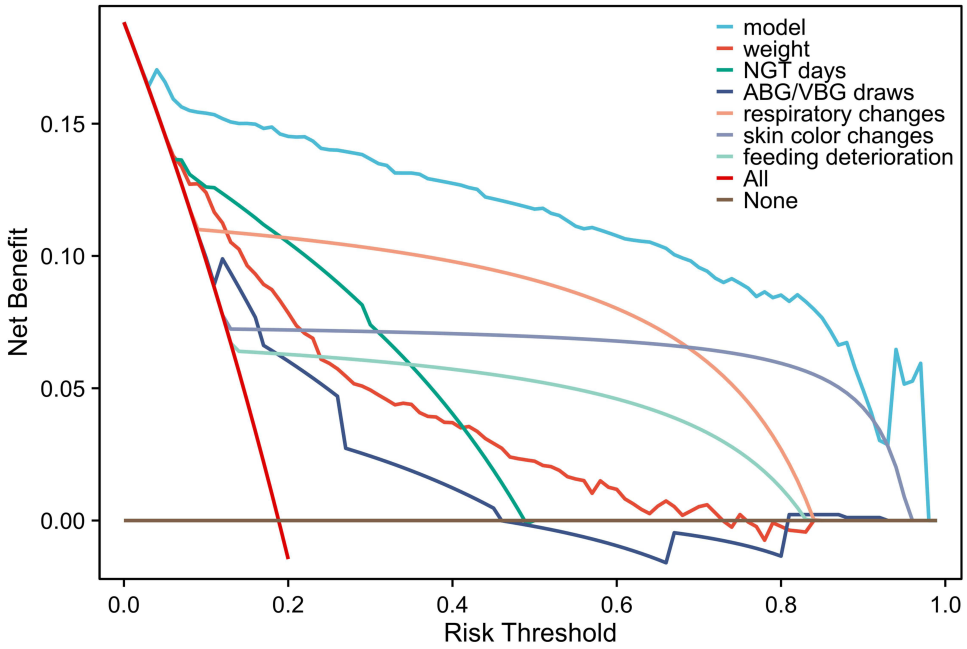

Figure 5 Results of the DCA of the predictive model and single indicator.

At present, there are many relevant indicators or models that can help to identify NI in the early stage. Huang established a predictive model for late-onset sepsis in preterm infants, which included four indicators like birth weight and the thyroid function, achieving an AUC of 0.855.[6] Sokou created a scoring model for early/late-onset sepsis in newborns, incorporating six indicators such as gestational age, changes in skin color, and C-reactive protein, with an AUC value of 0.918.[7] Sofouli developed a scoring system for predicting late-onset sepsis in newborns, which included a combination of laboratory indicators and a few clinical observational indicators, totaling eight indicators. The prediction accuracy rates for diagnosing sepsis were 39.31%, 40.69%, and 75.17% 48 hours before, 24 hours before, and on the day of diagnosis, respectively.[8] In contrast, the AUC value of the model in this study is 0.953.

However, most of indicators and models above were developed by clinicians. In addition to including the demographic characteristics of the patients, they tended to include objective indicators such as blood infection markers and imaging indicators. Although they had been shown to be helpful in predicting NI, the results from these indicators were not as timely as bedside observation.

The starting point of our study was based on the fact that nurses were close observers and primary caregivers for neonates in 24-hour bedside care settings. They had the earliest and most direct contact with preterm infants, enabling them to detect risk signals of NI early and accurately. This study attempted to establish a nurse-led model that is different from the previous clinician-led models, which mainly includes care-related operations and observational indicators, to identify NI at an earlier stage. To the best of our knowledge, this is the first nurse-led prediction model for NI in preterm infants in the NICU.

Skin color changes had the highest adjusted odds ratio in the model compared with the previous studies.[7,11,12] The skin is a reliable indicator of early changes in circulation and perfusion. Dark skin or skin patterns may be among the earliest clinical manifestations of infection.[11,13,14] As many as 51.6% of newborns with infections exhibit gray skin or patterned symptoms.[12] Because the body's resistance is weakened by various chronic diseases, the integrity of the skin and mucosal barrier is compromised and the immune system is suppressed. This allows pathogenic microorganisms to enter the bloodstream, produce large amounts of toxins and cause tissue damage, which in turn activates TNF, IL-1, IL-6, and other cytokines, leading to systemic inflammatory response syndrome (SIRS).[15] Additionally, activation of the complement system, coagulation system, kinin-releasing enzymes, kinin system and other pathways leads to microcirculatory dysfunction. This results in a pale, grayish face, mild cyanosis of the lips and nail beds, and mottled skin. If

this presentation occurs during clinical care, one must be alert for infection. Sokou's study categorized skin color changes into three grades: normal (bright pink or pinkish), moderate (mild or infrequent skin discoloration), and considerable (marked and persistent color change to greenish-gray),[7] which makes the nurses' observational assessment of skin color easier and more feasible.

The second independent predictor of NI in our study was the respiratory indicators, which can be easily obtained through nurse observation. Respiratory-related changes are the most common early signs of NI.[11] This is consistent with the most important predictive clinical variables identified in the literature.[8,11,12] Pishori found that 72.2% of infected patients exhibited symptoms of apnea, while research by Bury showed that the most common signs of late-onset sepsis were cardio-respiratory events, including increased respiratory rate and ventilatory support.[11,12] Infection-related respiratory changes usually initiate a systemic inflammatory response, as mentioned in the previous paragraph, and ultimately lead to alveolar-capillary barrier injury.[16] A multicenter retrospective study demonstrated that preterm infants with respiratory-related changes had a 2.65-fold heightened risk of NI in comparison to those without such symptoms.[14] Moreover, our study also demonstrated a 13.7-fold elevated risk of NI in preterm infants exhibiting respiratory changes as opposed to those who did not display such alterations. Nevertheless, further comprehensive studies are imperative to delineate the impact of NI on respiration.

Our findings showed that feeding deterioration was a significant predictor of NI, which aligns with previous studies.[8,11,12] These studies found that 65.1% of neonates with NI had feeding difficulties, such as reduction in feeding volume and changes in feeding pattern such as switching from autonomous feeding to nasogastric feeding or transitioning from feeding to fasting. The presence of a specific sign alone should not automatically raise suspicion of NI, rather, it is an alteration of that sign (an acute increase, a sudden onset) that should lead to the suspicion.[8,14] The deterioration of feeding in preterm infants with NI is primarily due to microvascular thrombosis, which increases leukocyte and platelet adhesion. Nitric oxide-induced vasodilation leads to abnormal vascular tone, contributing to microcirculatory dysfunction and multiorgan dysfunction. These factors ultimately reflect the fragile functional status of the neonatal gastrointestinal tract. Nurses play a crucial role in neonatal feeding, which also indicates the indispensable monitoring role of nurses in the management of NI in NICU.

Birth weight of the premature infant is a determinant of NI, being inversely and significantly correlated with sepsis occurrence.[10,12,17–21] This correlation was confirmed by our results. Javier report that the incidence rates of infection was inversely proportional to birth weight, with rates 2 to 4 times higher in those weighing between 1000 g and 1500 g than in other weight groups.[10,18] Among all cases of neonatal sepsis, the percentage of neonates weighing less than 2500g was 64.1%.[19] Late-onset sepsis rates are reported to be 1.6% in term infants, compared with 12–50% in very preterm and/or very low birth weight (VLBW) infants.[22] These findings can be attributed to three reasons. First, lower birth weight corresponds to immaturity in organ development and poorer physiological regulation, so premature infants have a weaker ability to eliminate invading bacteria.[23] Second, those also have lower levels of related antibodies like immunoglobulin G in the blood to protect themselves.[24] Finally, the presence of these factors increases the risk of complications, as well as the need for more invasive procedures and longer hospital stays, which also increases the risk of NI.

The number of arterial and venous blood draws and the duration of nasogastric tube placement, which are commonly employed invasive therapies in the treatment of premature infants, were also identified as independent predictors of NI. These invasive procedures result in damage to the infant's skin and mucosa, thereby destroying the infant's natural barrier, and facilitate the entry of pathogenic bacteria into the premature infant's system, which can subsequently lead to infection. As the number of arterial and venous blood draws and the duration of gastric tube placement increase, so too does the frequency and duration of high-risk environmental exposures, as does the risk of invasion by pathogenic microorganisms. In clinical practice, it is recommended that invasive procedures be avoided whenever possible. Concurrently, it is recommend initiating positive interventions such as breastfeeding and oral motor intervention as soon as the infant is ready. This approach may contribute to a reduction in the duration of gastric tube placement and a concomitant reduction in the risk of NI.

In summary, this nurse-led prediction model, which is presented as a nomogram, can easily and accurately assess the risk of NI. As a result, medical staff in clinical practice can identify NI that occurred at an early stage and provide more timely intervention.

However, our study also has several potential limitations. First, we acknowledge that our study was only a retrospective analysis, the omission of a small portion of data was unavoidable, which had been reasonably filled in. Second, this nomogram model was validated internally, although the results were good, a multicenter external validation would make our conclusions more convincing. In addition, because our study was nurse-led and included indicators focused on bedside observations, we did not use objective measures known to clinicians, such as laboratory measures and imaging measures. It might weaken the credibility of the conclusions to some extent, but this was precisely the theme that our study aimed to highlight—nurse-led. And at the same time, fewer variables also reduce the complexity and overfitting of the model. In the future, incorporating data from multicenter studies for external validation would enhance the reliability of the conclusions drawn in this article.

Conclusion

Skin color changes, respiratory-related changes, feeding deterioration, birth weight, days of gastric tube placement, and number of arterial and venous blood draws are the main independent predictors of NI in preterm infants. A nurse-led nomogram model constructed on the basis of these six predictors, which were primarily derived from nurses' observations, shows good predictive ability and is user-friendly for clinical staff in the NICU, especially nurses.

Ethics Approval and Informed Consent

This study complied with the Declaration of Helsinki, parent or legal guardian of the preterm infants provided verbal informed consent, which was approved by the Medical Ethics Committee of Renmin Hospital of Wuhan University and the relevant documents have been reviewed by the editors.

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Disclosure

The authors report no conflicts of interest in this work.

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