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Development and Validation of a Predictive Nomogram for Postpartum Hemorrhage in Pregnant Women: A Retrospective Study

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Background: Postpartum hemorrhage (PPH) remains a major contributor to maternal morbidity and mortality worldwide. Early identification of high-risk women is crucial for implementing targeted interventions. This study aimed to develop and validate a predictive nomogram that integrates key maternal and perinatal risk factors to estimate the risk of PPH.

Methods: In this retrospective study, 336 pregnant women who delivered at our hospital from January 2022 to January 2024 were included. PPH was defined as blood loss >500 mL after vaginal delivery or >1000 mL after cesarean section. Independent predictors were identified using forward stepwise multivariable logistic regression and incorporated into a nomogram. Discrimination was evaluated by the area under the receiver operating characteristic curve (AUC) and concordance index (C-index); calibration by the Hosmer–Lemeshow test and calibration curves; clinical utility by decision curve analysis (DCA). Internal validation used 1000 bootstrap resamples.

Results: Participants were classified into non-PPH (n = 281) and PPH (n = 55) groups. Independent predictors of PPH included advanced maternal age (≥35 years), uterine atony, various placental abnormalities (previa, abruption, adhesion, and retained placenta), adverse obstetric history, cesarean delivery, higher prenatal weight, instrumental delivery, birth canal tears, multiple gestations, macrosomia, coagulopathy, uterine fibroids, and adverse psychological status (all $p < 0.05$). The nomogram achieved an AUC of 0.786 (95% CI: 0.695–0.865) and a corrected C-index of 0.796. Calibration was excellent (Hosmer-Lemeshow, $p = 0.912$), and DCA confirmed its clinical utility.

Conclusion: This internally validated nomogram showed strong predictive performance for PPH using routinely collected clinical and psychosocial data. Future studies should conduct external validation and prospective multicenter evaluation to confirm its generalizability and clinical applicability.

Keywords: postpartum hemorrhage, predictive nomogram, risk stratification, obstetric outcomes, cesarean delivery

Introduction

PPH remains a significant contributor to maternal morbidity and mortality worldwide, particularly in low- and middle-income countries. Despite advances in obstetric care, PPH accounts for approximately 27% of maternal deaths globally, with its incidence ranging from 2% to 4% in vaginal deliveries and 6% to 7% in cesarean sections. Defined as blood loss exceeding 500 mL within 24 hours of vaginal delivery or 1000 mL following cesarean delivery, PPH can result in hypovolemic shock, coagulopathy, organ dysfunction, and ultimately, death if not managed promptly. Given its profound clinical and public health implications, the early identification of women at risk for PPH is a critical priority in obstetric care.[1–3]

Numerous risk factors for postpartum hemorrhage (PPH) have been identified, including uterine atony, retained placenta, abnormal placentation, prolonged labor, and a previous history of PPH. Other contributing factors such as advanced maternal age, high body mass index, multiple gestations, and coagulation disorders have also been linked to

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increased risk. However, the predictive accuracy of individual risk factors remains limited, highlighting the need for comprehensive models that integrate multiple clinical variables to improve risk stratification. Although several predictive models and nomograms for PPH have been proposed, most focus primarily on obstetric, fetal, and procedural parameters.[4,5] Psychosocial factors, particularly maternal psychological status, have received little attention, despite emerging evidence suggesting that psychological distress may adversely influence perinatal outcomes. To date, efforts to incorporate validated psychological assessments into visual risk prediction models for PPH remain limited, indicating an area that warrants further investigation. This represents a gap, as maternal psychological status remains underrepresented in existing PPH prediction frameworks despite its potential relevance.[6–8]

This study aimed to address this gap by developing and internally validating a clinically applicable nomogram for PPH, incorporating a comprehensive set of maternal, obstetric, fetal, and psychosocial variables. Special attention was given to evaluating the role of maternal psychological status, a potentially modifiable but often overlooked factor, in improving predictive accuracy. Using routinely collected clinical data, the model was designed to support individualized risk stratification and facilitate timely intervention, particularly in resource-constrained obstetric settings.

Methods

Study Design

This retrospective study was conducted at our hospital from January 2022 to January 2024 with the goal of developing a predictive nomogram for PPH. The study population comprised 336 pregnant women who met the following inclusion criteria: 1) completion of systematic prenatal examinations at our institution, 2) in-hospital delivery, 3) gestational age ≥28 weeks, and 4) availability of complete medical records including delivery mode, maternal age, parity, and documented intrapartum blood loss. Exclusion criteria were rigorously applied to eliminate confounding factors: 1) severe coagulation disorders or inherited bleeding diatheses, 2) elective pregnancy termination prior to labor, 3) uterine abnormalities (eg, fibroids, septate uterus) or prior uterine surgery (myomectomy/metroplasty), 4) significant pre-delivery trauma or hemostatic interventions, and 5) incomplete essential clinical data. Participants were stratified into two groups based on PPH occurrence: non-PPH group (n=281) and PPH group (n=55). The study's design and reporting adhered to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.[9] Informed consent was obtained from all subjects. The study was reviewed and approved by the Ethics Committee of Shanxi Children's Hospital, Shanxi Maternal and Child Health Hospital, Shanxi Obstetrics and Gynecology Hospital. All procedures followed relevant guidelines and adhered to the Declaration of Helsinki. Data was handled confidentially, with personal identifiers removed to protect participant privacy.

Diagnostic Criteria for Postpartum Hemorrhage

PPH was defined as cumulative blood loss ≥500 mL within 24 hours after vaginal delivery or ≥1000 mL within 24 hours after cesarean delivery, consistent with international diagnostic standards. Blood loss was quantitatively assessed in accordance with the World Health Organization (WHO) recommendations,[10] using a standardized and validated approach. For vaginal deliveries, the gravimetric method was applied: all blood-soaked materials (pads, sponges, and drapes) were weighed using calibrated electronic scales, and the dry weights were subtracted to obtain net blood loss. For cesarean deliveries, a combined gravimetric and volumetric method was used. Suction canisters were employed to collect intraoperative blood, and total blood volume was calculated by summing measured suction output with gravimetric estimates from surgical swabs and drapes. To ensure measurement accuracy and consistency among operators, all delivery room staff including obstetricians, midwives, and surgical nurses received standardized training in blood loss estimation techniques before the start of the study. The training was supervised by senior obstetricians and included protocol familiarization, hands-on practice, and periodic quality assurance checks throughout the study period.

Data Collection and Outcome Measures

Collection of baseline data: Maternal baseline characteristics included age, history of postpartum hemorrhage, infertility, number of previous miscarriages, parity, family history of difficult labor, early-pregnancy body mass index (BMI), prenatal weight, gestational age at delivery, fundal height during pregnancy, presence of uterine fibroids, coagulopathy, number of fetuses, fetal sex, neonatal birth weight, and mode of delivery. Additional obstetric variables collected were uterine atony, placenta previa, placental abruption, placental adhesion, retained placenta, use of assisted delivery techniques, birth canal tears, episiotomy, post-term pregnancy, and administration of uterine contraction inhibitors. As this was a retrospective study, data was extracted exclusively from electronic medical records. To minimize observer bias, two independent investigators, blinded to the study hypothesis and group allocation, performed data extraction and outcome assessment. All clinical variables, including postpartum blood loss estimates and psychological assessment scores, were independently verified by a senior obstetrician to ensure consistency and accuracy.

Psychological status: Maternal psychological well-being was assessed using the Self-Rating Anxiety Scale (SAS) and the Self-Rating Depression Scale (SDS). An SAS score below 50 indicated normal anxiety levels; scores of 50–60 reflected mild anxiety, 61–70 moderate anxiety, and scores above 70 severe anxiety. Similarly, an SDS score below 50 indicated no depression; scores of 50–60, mild depression; 61–70, moderate depression; and scores above 70, severe depression. An SAS score ≥50 or an SDS score ≥50 was considered indicative of adverse psychological status. Psychological assessments were performed during the third trimester (32–36 weeks of gestation) by trained clinical psychologists with over eight years of clinical experience, following standardized administration procedures.

Statistical Analysis

Statistical analyses were conducted using SPSS version 26.0 and R language version 3.6.3. Continuous variables were expressed as mean ± standard deviation and compared between groups using independent samples *t*-tests. Categorical variables were presented as frequencies (percentages) and analyzed using the chi-square test, continuity correction chi-square test, or Fisher's exact test as appropriate. Forward stepwise multivariate logistic regression was performed to identify risk factors for postpartum hemorrhage, yielding odds ratios (ORs) and their corresponding 95% confidence intervals (CIs). The rms package in R was employed to construct a nomogram for predicting postpartum hemorrhage risk. Receiver operating characteristic (ROC) curves were plotted to evaluate the model's discriminative ability, and the concordance index (C-index) was calculated. The optimal cutoff value was determined based on the maximum Youden index, allowing for the determination of the model's sensitivity and specificity. Calibration of the model was assessed using the Hosmer-Lemeshow goodness-of-fit test. Internal validation was performed through 1000 bootstrapped samples, and a corrected C-index was calculated. Calibration curves were generated to visually assess the predictive accuracy of the nomogram. The clinical utility of the model was assessed using decision curve analysis (DCA). A p-value < 0.05 was considered statistically significant.

Results

Univariate Analysis of Maternal and Perinatal Factors Associated with Postpartum Hemorrhage

The univariate analysis revealed significant differences in several maternal and perinatal factors between women who experienced PPH and those who did not. Maternal age was significantly higher in the PPH group (33.40 ± 2.00 years) compared to the non-PPH group (25.80 ± 7.00 years; $p < 0.05$). Placental abnormalities, including placenta previa, placental abruption, placental adhesion, and retained placenta, were all more frequently observed in the PPH group ($p < 0.05$). Obstetric history factors, such as a prior history of PPH, infertility, multiple miscarriages, and multiparity, were significantly associated with increased PPH risk. Among pregnancy-related factors, antepartum hemorrhage and cesarean delivery were more common in the PPH group ($p < 0.05$), as was a higher prenatal weight. Additionally, birth canal factors, including instrumental delivery and birth canal tears, were more frequent among women with PPH ($p < 0.05$). Fetal factors, such as macrosomia and multiple gestations, also showed significant associations with PPH ($p < 0.05$). Although the frequency of male fetuses did not differ significantly between groups, coagulopathy and uterine fibroids were more prevalent in the PPH

Table 1 Univariate Analysis of Maternal and Perinatal Factors Associated with Postpartum Hemorrhage

Variable	Non-PPH Group (n = 281)	PPH Group (n = 55)	t/χ^2 Value	P value
Age (years)	25.81 ± 7.06	33.40 ± 5.68	7.51	<0.05
Uterine atony	22 (7.83%)	7 (12.73%)	6.75	<0.05
Placental factors				
Placenta previa	7 (2.49%)	4 (7.27%)	10.52	<0.05
Placental abruption	8 (2.85%)	7 (12.73%)	37.61	<0.05
Placental adhesion	0 (0.00%)	1 (1.82%)	4.40	<0.05
Retained placenta	7 (2.49%)	5 (9.09%)	155.02	<0.05
Obstetric history				
History of PPH	5 (1.78%)	5 (9.09%)	235.01	<0.05
Infertility history	10 (3.56%)	9 (16.36%)	69.28	<0.05
Miscarriages ≥2 times	28 (9.96%)	7 (12.73%)	45.03	<0.05
Parity ≥2	4 (1.42%)	2 (3.64%)	12.81	<0.05
Family history of dystocia	7 (2.49%)	4 (7.27%)	139.06	<0.05
Pregnancy factors				
Antepartum hemorrhage	10 (3.56%)	4 (7.27%)	157.18	<0.05
Early-pregnancy BMI (kg/m^2)	21.35 ± 2.42	21.56 ± 2.43	0.58	0.56
Delivery factors				
Cesarean delivery	28 (9.96%)	10 (18.18%)	293.53	<0.05
Gestational age at delivery (weeks)	38.40 ± 1.96	38.60 ± 2.04	1.91	0.06
Prenatal weight (kg)	63.50 ± 4.30	69.00 ± 4.50	25.5	<0.05
Fundal height ≥36 cm	169 (60.14%)	37 (67.27%)	283.28	<0.05
Birth canal factors				
Instrumental delivery	7 (2.49%)	4 (7.27%)	70.18	<0.05
Birth canal tear	18 (6.41%)	9 (16.36%)	48.06	<0.05
Episiotomy	65 (23.13%)	11 (20.00%)	42.51	<0.05
Fetal factors				
Multiple gestation	2 (0.71%)	1 (1.82%)	13.05	<0.05
Macrosomia	12 (4.27%)	7 (12.73%)	30.04	<0.05
Male fetus	143 (50.89%)	28 (50.91%)	3.40	0.06
Coagulopathy	0 (0.00%)	2 (3.64%)	10.17	<0.05
Uterine fibroids	10 (3.56%)	3 (5.45%)	13.28	<0.05
Adverse psychological status	48 (17.08%)	12 (21.82%)	63.9	<0.05

Abbreviation: BMI, Body Mass Index.

group ($p < 0.05$). Finally, adverse psychological status was more commonly observed in women with PPH ($p < 0.05$) (Table 1).

Bonferroni correction was applied in Supplementary Table 1. After adjustment, all variables that were originally statistically significant remained significant at the adjusted threshold ($p < 0.0026$), confirming the robustness of the univariate findings. Early-pregnancy BMI, gestational age at delivery, and fetal sex did not reach statistical significance before or after adjustment.

Multivariate Logistic Regression Analysis of Risk Factors Associated with Postpartum Hemorrhage

The multivariate analysis identified several independent factors significantly associated with PPH. Advanced maternal age (≥35 years) increased the odds of PPH (OR 1.34, 95% CI: 1.17–1.56, $p < 0.05$), while uterine atony demonstrated a particularly strong association, with women experiencing this condition being over 13 times more likely to have PPH (OR 13.06, 95% CI: 10.49–15.69, $p < 0.05$). Among placental factors, placenta previa, placental abruption, placental adhesion, and retained placenta were all significantly associated with elevated PPH risk (all $p < 0.05$), with retained placenta showing the highest odds ratio of 7.38 (95% CI: 6.61–8.10). In terms of obstetric history, women with a prior history of PPH had more than double the risk (OR 2.20, 95% CI: 1.68–2.71, $p < 0.05$). Infertility history, multiple miscarriages, increased parity, and a family history of dystocia also emerged as significant risk factors (all $p < 0.05$). Antepartum hemorrhage further contributed to a greater likelihood of PPH (OR 2.03, 95% CI: 1.54–2.50, $p < 0.05$). Delivery-related factors were likewise important, with cesarean delivery increasing PPH odds (OR 2.16, 95% CI: 1.96–2.29, $p < 0.05$). Notably, higher prenatal weight and increased fundal height (≥36 cm) showed significant associations, although their odds ratios suggested differing levels of risk (both $p < 0.05$). Birth canal factors including instrumental delivery and birth canal tears were also independently associated with higher PPH risk (both $p < 0.05$). In addition, fetal factors such as multiple gestation and macrosomia were significant predictors (both $p < 0.05$). Coagulopathy showed one of the strongest associations, with an odds ratio of 8.43 (95% CI: 6.30–10.40, $p < 0.05$). Finally, uterine fibroids and adverse psychological status were found to be independent risk factors for PPH (both $p < 0.05$) (Table 2).

To assess multicollinearity, variance inflation factors (VIFs) were calculated for each predictor. All VIFs ranged from 1.05 to 1.30, indicating no significant multicollinearity among variables (Supplementary Table 2).

Construction of a Nomogram for Predicting Postpartum Hemorrhage

A predictive nomogram for postpartum hemorrhage was constructed using the significant risk factors identified from multivariate logistic regression analysis. By summing the assigned scores of each variable, a total score is obtained. The total score corresponds to a probability on the nomogram's lower axis, reflecting the predicted risk of postpartum hemorrhage. Higher total scores are associated with a greater likelihood of postpartum hemorrhage (Figure 1).

Discrimination of the Nomogram Model

To assess the discriminative ability of the predictive nomogram for postpartum hemorrhage, the total risk score was used as the independent variable, while the occurrence of postpartum hemorrhage served as the dependent variable. The model's ROC curve yielded an AUC of 0.786 (95% CI: 0.695–0.865), indicating moderate to strong discrimination. Using the threshold corresponding to the maximum Youden index, the model demonstrated a sensitivity of 85.61% and a specificity of 73.56% (Figure 2).

Calibration of the Nomogram Model

Internal validation was performed using the Bootstrap resampling method, with 1000 repetitions, to assess the calibration of the predictive model. The corrected concordance index (C-index) was 0.796 (95% CI: 0.713–0.865), demonstrating good consistency and indicating that the model has strong discriminatory ability. The Hosmer-Lemeshow goodness-of-fit test yielded a χ^2 value of 2.859 with a p-value of 0.912, suggesting a well-calibrated model. The calibration curve further indicated that the predicted probabilities closely matched the actual probabilities, highlighting the model's strong calibration performance (Figure 3).

Clinical Utility of the Nomogram Model

The DCA illustrated the clinical usefulness of the predictive nomogram. In the DCA plot, the horizontal line represents the scenario in which no PPH events occur and no interventions are undertaken, resulting in zero net benefit. Conversely, the diagonal line reflects a scenario where all women experience PPH and receive interventions, yielding a negative net benefit.

Table 2 Multivariate Logistic Regression Analysis of Risk Factors for Postpartum Hemorrhage

Factors	β Value	Standard Error Value	Wald Value	OR Value	95% CI for OR	P-value
Age ≥35 years	1.31	0.861	2.45	1.34	(1.17–1.56)	<0.05
Uterine atony	1.074	0.899	3.35	13.06	(10.49–15.69)	<0.05
Placental factors						
Placenta previa	0.912	1.206	4.3	5.74	(4.35–7.08)	<0.05
Placental abruption	0.712	1.612	2.96	4.98	(4.89–5.11)	<0.05
Placental adhesion	1.29	1.481	3.34	6.92	(5.82–7.50)	<0.05
Retained placenta	1.71	1.828	1.69	7.38	(6.61–8.10)	<0.05
Obstetric history						
History of PPH	0.92	1.994	4.99	2.2	(1.68–2.71)	<0.05
Infertility history	0.884	1.411	3.31	1.9	(1.39–2.49)	<0.05
Miscarriages ≥2 times	1.189	1.645	2.47	2.27	(1.90–2.62)	<0.05
Parity ≥2	1.225	1.521	4.37	2.2	(1.93–2.56)	<0.05
Family history of dystocia	1.142	1.272	1.65	2.02	(1.66–2.38)	<0.05
Antepartum hemorrhage	1.63	1.063	1.89	2.03	(1.54–2.50)	<0.05
Delivery factors						
Cesarean delivery	0.654	1.394	2.14	2.16	(1.96–2.29)	<0.05
Prenatal weight	0.853	1.658	4.93	0.25	(0.10–0.38)	<0.05
Fundal height ≥36 cm	0.732	1.432	2.55	0.49	(0.23–0.51)	<0.05
Birth canal factors						
Instrumental delivery	1.106	1.306	2.89	2.38	(2.00–2.83)	<0.05
Birth canal tear	1.394	1.454	2.62	2.18	(1.53–2.76)	<0.05
Fetal factors						
Multiple gestation	0.98	1.274	3.12	2.49	(2.07–3.05)	<0.05
Macrosomia	1.4	1.37	4.17	1.92	(1.22–2.64)	<0.05
Coagulopathy	1.26	1.2	3.43	8.43	(6.30–10.40)	<0.05
Uterine fibroids	1.66	1.182	3.01	1.24	(1.10–1.44)	<0.05
Adverse psychological status	1.38	1.18	2.62	6.29	(4.73–7.84)	<0.05

Abbreviations: β, regression coefficient; OR, odds ratio; CI, confidence interval.

Compared to these extreme strategies, the nomogram model demonstrated significantly higher net benefit, indicating robust clinical utility and the potential to improve decision-making in managing postpartum hemorrhage (Figure 4).

Power Analysis and Sample Size Considerations

We performed a post hoc power analysis for key predictors identified in the multivariable model. The factors selected for power analysis included uterine atony, coagulopathy, placenta previa, placental abruption, placental adhesion, retained placenta, cesarean delivery, birth canal tear, and macrosomia. The calculated power for these variables was as follows: uterine atony (near 100%), coagulopathy (near 100%), placenta previa (near 100%), placental abruption (near 100%), placental adhesion (near 100%), retained placenta (near 100%), cesarean delivery (near 90%), birth canal tear (near 90%), and macrosomia (near 85%). Given that the power for all key variables exceeded 80%, we conclude that our sample size was sufficiently robust to detect meaningful associations with high statistical reliability.

Discussion

PPH remains one of the leading causes of maternal morbidity and mortality worldwide, particularly in low-resource settings where timely intervention may be limited. Despite advances in obstetric management, accurately predicting and

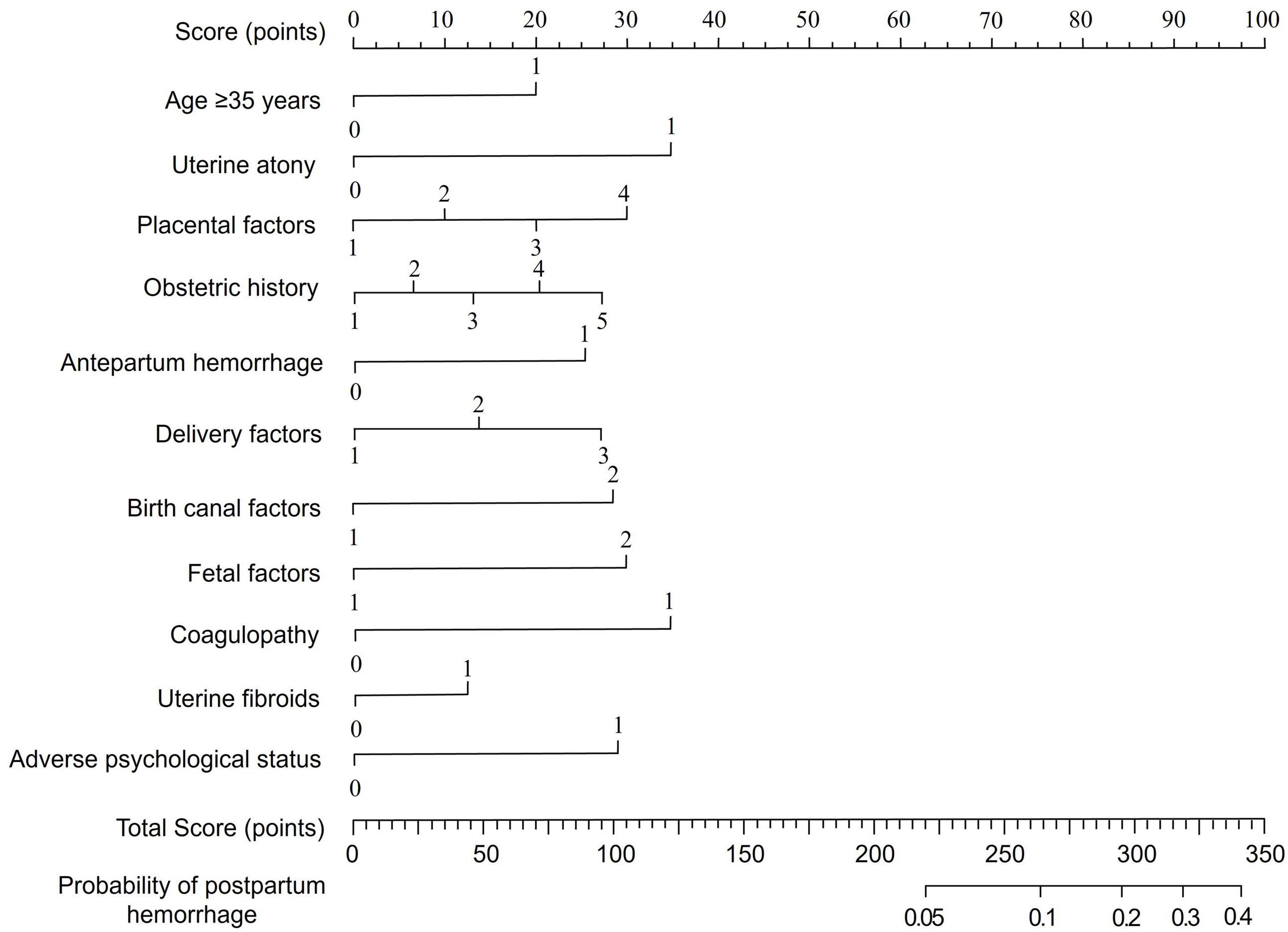

Figure 1 Nomogram for predicting postpartum hemorrhage.

preventing PPH continues to pose a major clinical challenge. The etiology of PPH is multifactorial, involving uterine atony, abnormal placentation, coagulation disorders, and delivery-related trauma. Given this complexity, developing a comprehensive predictive model that integrates multiple maternal and perinatal factors is crucial for early identification and proactive management of high-risk patients.[11–13] In this retrospective study, we constructed a predictive nomogram for PPH based on significant maternal and perinatal predictors identified through univariate and multivariate analyses. The model demonstrated moderate to strong discriminative ability (AUC = 0.786) and good calibration (corrected C-index = 0.796), with decision curve analysis confirming potential clinical utility. As detailed in the methodology, internal validation was rigorously performed using the bootstrap resampling method with 1000 iterations, showing stable model performance and good calibration (Hosmer–Lemeshow $\chi^2 = 2.859$, $p = 0.912$).

Advanced maternal age (≥35 years) emerged as a significant risk factor for PPH. Age-related changes, such as decreased uterine contractility and vascular elasticity, may predispose older women to suboptimal myometrial response during the postpartum period. Additionally, older mothers are more likely to experience comorbidities and placental abnormalities, which can further impair uterine hemostasis. These factors likely contribute to the observed increased odds of PPH in this population.[14,15] Uterine atony was identified as the most potent predictor, with an odds ratio exceeding 13. Uterine atony, defined as the failure of the uterus to contract adequately after delivery, is a well-known cause of PPH. The underlying mechanism involves the inability of the myometrium to constrict sufficiently, which may result from overdistension due to multiple gestations or macrosomia, prolonged labor, or previous uterine surgeries. When uterine contractions are inadequate, the spiral arteries remain patent, leading to significant blood loss. The strong association observed in our study underscores the critical role of uterine contractility in preventing PPH.[16,17]

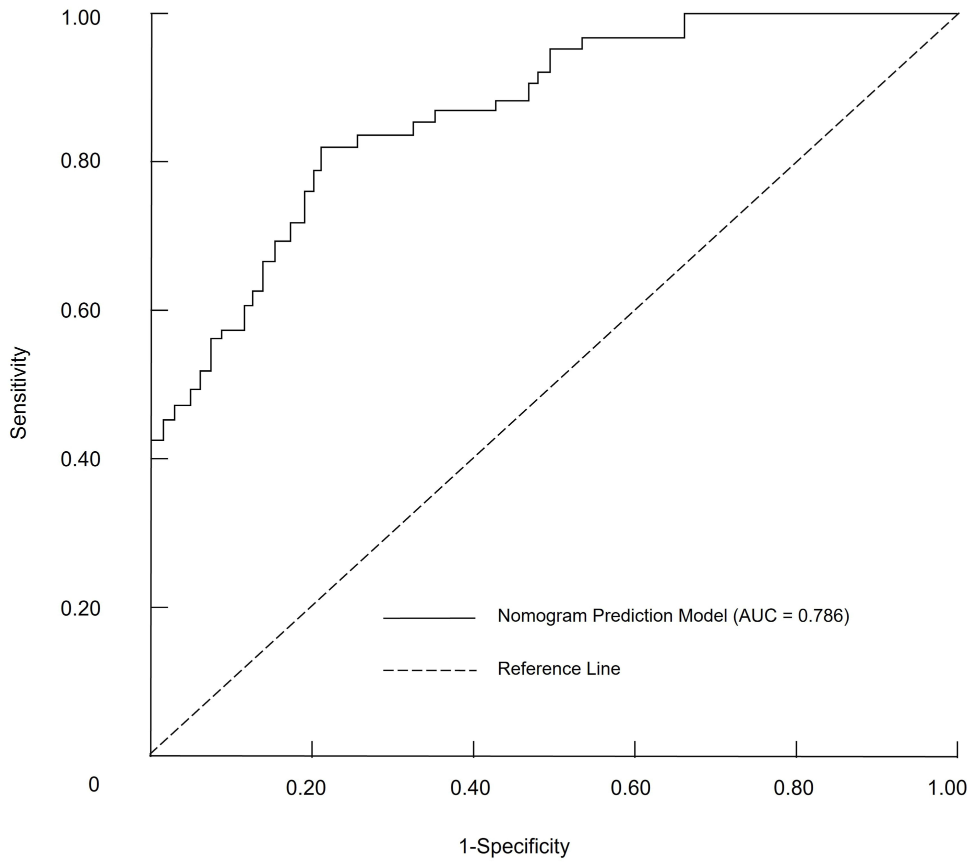

Figure 2 Receiver operating characteristic (ROC) curve of the nomogram for predicting postpartum hemorrhage.

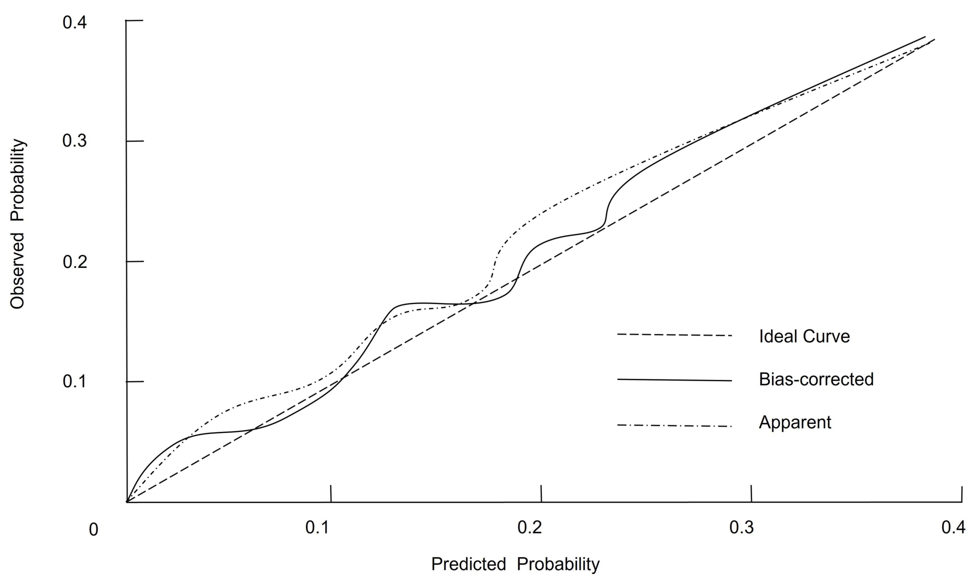

Figure 3 Calibration curve of the nomogram for predicting postpartum hemorrhage.

Placental abnormalities, including placenta previa, placental abruption, placental adhesion, and retained placenta, were consistently associated with an increased risk of PPH. These conditions interfere with normal placental separation and impair effective uterine contraction. For example, placenta previa involves implantation in the lower uterine segment,

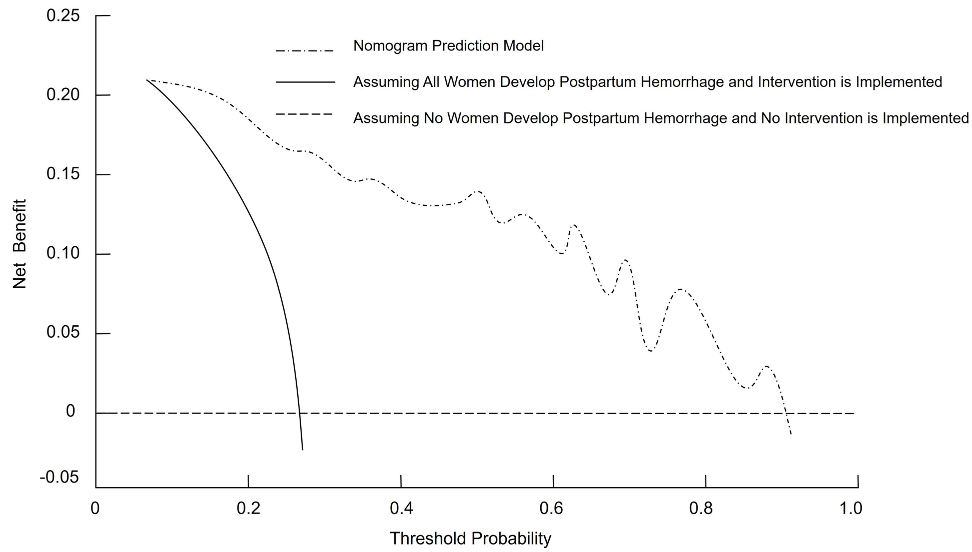

Figure 4 Decision curve analysis (DCA) of the nomogram for predicting postpartum hemorrhage.

an area with less muscular support, thereby compromising effective hemostasis. Similarly, placental abruption can lead to premature separation of the placenta, resulting in bleeding from exposed uterine vessels. Retained placenta and placental adhesions impede complete placental delivery, leaving behind areas of bleeding.[18,19] Collectively, these factors highlight the importance of careful placental evaluation during prenatal care and delivery. Obstetric history factors, such as a previous history of PPH, infertility, multiple miscarriages, and increased parity, also contributed to the risk profile. A prior episode of PPH may reflect an underlying predisposition, such as uterine or coagulation abnormalities, that persists in subsequent pregnancies. Infertility and recurrent miscarriages may indicate underlying endometrial or hormonal disturbances that adversely affect placental implantation and uterine contractility. Multiparity, by leading to cumulative uterine stretching and possible muscle fatigue, may diminish the uterus's ability to contract effectively post-delivery.[20]

Antepartum hemorrhage and cesarean delivery were additional pregnancy-related factors associated with an elevated risk of PPH. Antepartum hemorrhage often signifies underlying placental or uterine pathology, which can extend into the postpartum period. Cesarean delivery, although sometimes necessary, is associated with increased blood loss due to surgical trauma and the potential for abnormal placentation in future pregnancies. Furthermore, higher prenatal weight and increased fundal height (≥36 cm) may be surrogate markers for uterine overdistension, thereby increasing the likelihood of uterine atony.[21,22] Birth canal factors, including instrumental delivery and birth canal tears, were independently associated with PPH. Instrumental delivery can cause mechanical trauma to the cervix and vagina, leading to lacerations that contribute to hemorrhage. Birth canal tears similarly disrupt tissue integrity, exacerbating blood loss during delivery. Fetal factors, such as multiple gestation and macrosomia, further compound the risk of PPH. These conditions contribute to uterine overdistension, which is known to impair myometrial contractility.[23,24] Additionally, coagulopathy, one of the strongest predictors in our study, directly impairs the clotting cascade and hemostatic processes, leading to uncontrolled bleeding. Uterine fibroids may interfere with normal uterine contractions and placental detachment, further increasing hemorrhagic risk. Finally, adverse psychological status was associated with PPH. Although the mechanistic link is less direct, psychological stress may influence neuroendocrine responses, potentially affecting uterine contractility and the timing of seeking medical intervention, thereby indirectly contributing to increased risk.[25]

Our model introduces maternal psychological status as a novel and independent predictor of PPH. Psychological distress, evaluated using validated third-trimester instruments (SAS and SDS), showed a strong association with PPH (OR 6.29, $p < 0.05$), underscoring a potential psychosocial risk factor rarely incorporated into existing models. This finding expands the current understanding of PPH etiology and highlights the importance of integrating mental health screening into perinatal care. Furthermore, the comprehensiveness of our model, which incorporates maternal history, placental pathology, delivery characteristics, and fetal parameters, accurately reflects the multifactorial nature of postpartum hemorrhage. This broad inclusion enhances clinical relevance and may improve risk stratification in diverse settings, especially where advanced tools are limited. The model's comprehensiveness further strengthens its predictive value. It incorporates a broad spectrum of clinical variables reflecting the multifactorial etiology of PPH and demonstrated good calibration and discriminative power upon internal validation. Moreover, the model was developed in a resource-constrained clinical setting, which enhances its potential applicability in low- and middle-income countries where timely intervention is often limited. From a clinical perspective, the model provides actionable guidance for frontline healthcare providers, particularly nursing staff. Incorporating this nomogram into routine perinatal assessment may support early identification of high-risk patients, facilitate individualized monitoring strategies, and optimize the use of uterotonics and emergency protocols. Addressing psychological risk through antenatal counseling may further enhance maternal outcomes.[26,27] Taken together, this integrative tool holds promise for improving PPH prevention and care in diverse obstetric settings. To improve clinical utility, a detailed example illustrating how the nomogram can be applied in clinical practice is provided in Supplementary Appendix 1.

Several recent studies have proposed predictive models for PPH in specific obstetric subgroups. Lei[28] developed a nomogram for twin cesarean deliveries, incorporating six intraoperative and fetal predictors; however, the model showed only modest discrimination (AUC = 0.722) and was limited in generalizability due to its narrow clinical focus. In contrast, our model targets a broader obstetric population and integrates underexplored psychosocial factors, enhancing its applicability to routine obstetric care. Similarly, Zhang et al[29] established a high-performing nomogram for PPH prediction in women with hypertensive disorders of pregnancy (HDP), relying on laboratory-based biomarkers such as endothelin and fibrinogen (AUC > 0.88). While their model demonstrates excellent discrimination, its dependence on laboratory indices may limit timely clinical implementation in resource-constrained settings. Our approach, which relies on clinically observable variables such as maternal psychological status, enables practical application in routine obstetric care without the need for advanced diagnostic resources. Zhou et al[30] constructed a logistic model for non-primiparous women undergoing vaginal delivery, identifying conventional obstetric factors such as BMI and placenta previa. Although methodologically similar, their model was population-restricted and did not consider psychological determinants. By encompassing a wider range of maternal, fetal, and psychosocial variables, our nomogram better captures the multifactorial nature of PPH risk and contributes novel insights to predictive modeling in general obstetric cohorts.

This study has several limitations. First, its retrospective design may introduce inherent selection bias and limit causal inference regarding identified PPH risk factors. Second, while we extracted data from comprehensive medical records, some clinically relevant variables may have been underreported or missing, which could have influenced model performance. Third, although the nomogram demonstrated favorable internal validity, reflected by robust calibration and discrimination, external validation was not performed due to the absence of an independent cohort and limited research resources. This restricts the generalizability of the model beyond the current single-center population. Regarding methodological considerations, forward stepwise logistic regression was employed for predictor selection to balance model interpretability and overfitting risk in a moderately sized dataset. However, we acknowledge that more contemporary approaches such as LASSO regression may offer enhanced variable selection stability and predictive robustness. Additionally, the model relies on clinically observable and routinely available variables, including maternal psychological status, which enhances its practicality and facilitates implementation in obstetric care, particularly in resource-limited settings. Future research should aim to prospectively validate and refine the nomogram in larger, multicenter cohorts with greater diversity. Integration of longitudinal data, advanced imaging, and emerging biomarkers may further enhance predictive accuracy and allow for more personalized preventive strategies. We are actively exploring opportunities for multicenter collaboration to advance this work.

Conclusions

In conclusion, our retrospective study developed and validated a predictive nomogram integrating key maternal and perinatal risk factors for postpartum hemorrhage. The model demonstrated robust discrimination (AUC 0.786) and calibration (C-index 0.796), supporting its clinical utility. This tool may significantly enhance early risk stratification, guide targeted interventions, and ultimately reduce maternal morbidity and mortality. Future studies should perform external validation and prospective multicenter evaluation to confirm the model's generalizability and clinical applicability.

Data Sharing Statement

The datasets used and/or analyzed during the present study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Shanxi Children's Hospital, Shanxi Maternal and Child Health Hospital, Shanxi Obstetrics and Gynecology Hospital. All procedures involving human participants were conducted in accordance with institutional and national ethical standards, as well as the 1964 Helsinki Declaration and its amendments. Informed consent was obtained from all participants.

Consent for Publication

Informed consent was obtained from all subjects.

Disclosure

The authors declare that they have no competing interests.

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