

Prediction of Postpartum Hemorrhage Using Regression-Based Models: A Multicenter Retrospective Study Involving Two Centers

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Abstract

Background

Postpartum hemorrhage (PPH) remains a leading cause of maternal morbidity and mortality worldwide. Early identification of high-risk women is critical for timely intervention. This study aimed to develop and validate a predictive model for PPH using clinical and laboratory parameters.

Methods

This a multicenter retrospective study involving two centers, included 540 women with gestational weeks ≥ 28 who delivered at Shandong Provincial Hospital and Shandong Provincial Maternal and Child Health Care Hospital between 2019 and 2021. PPH was defined as blood loss ≥ 1000 milliliters within 24 hours after delivery. Sociodemographic and clinical data were collected, and univariate and multivariate logistic regression analyses were used to identify independent risk factors for PPH, which were then incorporated into a predictive model. Calibration plots, receiver operating characteristic (ROC) curve and area under the curve (AUC), and decision curve analysis (DCA) were used to evaluate the performance of the model.

Results

Significant predictors of PPH included advanced maternal age, primiparity, assisted reproductive pregnancy, preterm birth, body mass index, prolonged menstrual duration, placenta previa or low-lying placenta, thrombocytopenia, shortened activated partial thromboplastin time (APTT), and low fibrinogen. The predictive model demonstrated good calibration (Hosmer-Lemeshow $\chi^2 = 10.053$, $P > 0.05$), satisfactory discrimination (AUC = 0.729; 95% CI, 0.686–0.772), and meaningful net clinical benefit on DCA.

Conclusions

This regression-based predictive model can identify women at high risk of PPH, providing a practical tool for early risk stratification and individualized clinical management.

1. Introduction

Postpartum hemorrhage (PPH) is widely recognized as the primary direct cause of maternal morbidity and mortality worldwide. According to the report of the World Health Organization (WHO), PPH accounts for more than a quarter of the total maternal deaths worldwide[1, 2]. Approximately 14 million women experience PPH each year, leading to about 70,000 maternal deaths[3]. Although PPH-related deaths have significantly decreased in high-income countries (HICs) due to well-developed healthcare systems and effective preventive measures, PPH remains a serious public health challenge in low- and middle-income

countries (LMICs)[4]. Globally, PPH accounts for 8% of maternal deaths in developed countries and 20% of maternal deaths in developing countries[5]. The latest evidence from multiple developed countries indicates that the incidence of PPH is rising[6], especially the preventable PPH [7].

The definition of PPH has undergone evolution. Traditionally, postpartum hemorrhage was considered to be ≥ 500 mL of blood loss from vaginal delivery or ≥ 1000 mL of blood loss from cesarean section[8], but visual estimation often underestimates the amount of blood loss. In 2017, the American College of Obstetricians and Gynecologists (ACOG) redefined PPH as: cumulative blood loss of ≥ 1000 mL, or clinical manifestations of hypovolemic shock, without distinguishing the mode of delivery[9]. This transformation reflects the advancement of diagnostic concepts, shifting from mere reliance on blood loss to focusing on changes in vital signs, such as tachycardia, low blood pressure, dizziness, and pale complexion, which are more direct danger signals[10, 11].

Clinically, the etiology of PPH is usually summarized in the "4T" framework: Tone (uterine atony), Trauma (birth canal injury), Tissue (placental retention), and Thrombin (coagulation disorder)[12]. In addition to the direct causes covered by the "4T" framework, the risk factors for PPH can be categorized according to their occurrence at different stages of the birthing process, which helps in effective risk identification and intervention during pregnancy. Moreover, the risk of PPH is also related to various maternal and birthing-related factors, such as advanced maternal age, multiple pregnancies, obesity, anemia, pregnancy-induced hypertension, placental abnormalities, abnormal labor, excessive use of oxytocin, cesarean section, and instrumental delivery[13].

The study shows that the risk of PPH in elderly mothers (≥ 35 years old) significantly increases, with an odds ratio (OR) of 1.96 in one study. In addition, pregnant women with a history of PPH or preterm birth, obesity (BMI > 35), anemia, and those suffering from pregnancy-induced hypertension have a higher risk of PPH as well[14]. Multiple pregnancies, macrosomia (neonatal weight > 4 kilograms), and placental abnormalities (placenta previa, placental abruption) all increase the risk of PPH. Studies on neonates weighing more than 4 kilograms show that their PPH risk odds ratio is as high as 3.92[15]. Extended or rapid labor, excessive use of oxytocin, cesarean section, and instrumental delivery interventions during the birthing process can all lead to PPH[16]. The occurrence of neonatal asphyxia is significantly associated with PPH risk, with an adjusted odds ratio as high as 5.52[15].

However, most of these studies are limited to univariate or multivariate analysis, and the relative importance and interaction of risk factors have not been fully explored.

Given the huge burden of PPH and the limitations of existing risk prediction models, there is an urgent need to develop robust, clinically applicable models to accurately identify high-risk pregnant women before or during delivery. Such models will help with personalized monitoring, guide preventive interventions, and optimize the allocation of obstetric resources.

Therefore, this study aims to (i) investigate maternal, obstetric, and antenatal factors related to PPH; (ii) construct and validate a PPH prediction model based on clinical and laboratory indicators. This model is

expected to enable early identification of high-risk populations and individualized interventions, thereby reducing maternal and perinatal morbidity and mortality related to PPH.

2. Materials and Methods

2.1. Study Design and Patients

This retrospective study was conducted under the ethical approval of the Institutional Review Board (approval number: SWYX: NO.2021 – 532). Due to the retrospective nature of the analysis, the requirement for informed consent was waived.

This is a retrospective study conducted by the Obstetrics and Gynecology Department of Department of Obstetrics and Gynecology of Shandong Provincial Hospital and Shandong Provincial Maternal and Child Health Care Hospital from January 2019 to December 2021. The medical records system was searched with "PPH" as the diagnostic label, and a total of 103 cases (Shandong Provincial Hospital) and 196 cases (Shandong Provincial Maternal and Child Health Hospital) were included. After a secondary review of the case information, 29 cases were excluded (including 11 cases with blood loss < 1000ml; 10 cases with gestational age < 28 weeks; and 8 cases with incomplete information). Finally, 270 patients met the inclusion criteria (gestational age ≥ 28 weeks), and non-PPH (normal control group, NC) patients were selected in a 1:1 matching manner, resulting in a total of 540 female participants. The diagnosis of PPH was based on the ACOG criteria: blood loss ≥ 1000 milliliters within 24 hours of vaginal delivery or cesarean section. Exclusion criteria included: blood loss < 1000ml; gestational age < 28 weeks at delivery; or missing core variable data (Fig. 1).

2.2. Data Collection

2.2.1. Blood Loss Measurement Methods:

This study uses three commonly used clinical methods for blood loss assessment, including the volume method, weight method, and suction pot method.

- **Volume Method:** Suitable for vaginal delivery. After the amniotic membrane rupture and amniotic fluid expulsion, a special kidney-shaped bowl is placed at the perineum to collect the blood. The container is removed 2 hours postpartum, and the blood volume is measured using a measuring cup.
- **Weight Method:** Suitable for vaginal delivery. The blood-soaked gauze, bedding, and towels used postpartum are collected, sealed, and weighed together. The blood loss is calculated by subtracting the prepartum weight from the postpartum weight. The conversion is based on the ratio of weight (g) to volume (mL) = 1.05:1. The total blood loss for vaginal delivery is the sum of the results from the volume method and the weight method.
- **Suction Pot Method:** Suitable for cesarean section. After cutting the uterine wall and expelling the amniotic fluid, a vacuum aspirator is used to collect the blood, which is then poured into a measuring

cylinder for measurement.

2.2.2. Research Variables:

- Basic Information: Admission route, admission timing, gestational age at admission, pregnancy and childbirth history, method of conception, fetal age at delivery, mode of delivery, delivery timing, maternal age, age, height, weight, body mass index (BMI), menstrual status, etc.
- Obstetrics: Scarred uterus, history of PPH, gestational age > 41 weeks or < 37 weeks, multiple pregnancy, chorioamnionitis, uterine fibroids, polyhydramnios, preeclampsia, placenta previa or low-lying placenta, known or suspected placenta accreta disease, placental abruption or active bleeding, known coagulation disorders, HELLP syndrome, intrauterine fetal death, level of platelets, level of hematocrit (Hct), level of hemoglobin (Hb)[17].
- Others: Anemia, oligohydramnios, macrosomia, body temperature rises, premature rupture of membranes (PROM), thrombosis, etc.
- Fetus: Number of fetuses, birth weight, Apgar score
- Laboratory Tests: Complete blood count, coagulation function, liver function, and biochemical indicators included white blood cell (WBC) count, red blood cell (RBC) count, Hb, Hct, platelet (PLT) count, fibrin degradation products (FDP), prothrombin time (PT), international normalized ratio (INR), APTT, fibrinogen (Fib), alanine aminotransferase (ALT), aspartate aminotransferase (AST), total protein, albumin, total cholesterol, high-density lipoprotein (HDL), low-density lipoprotein (LDL), small dense low-density lipoprotein (sdLDL), triglycerides.

2.3. Statistical Analysis

All statistical analyses were performed using **R software (version 4.5.0, R Foundation for Statistical Computing, Vienna, Austria)**. Continuous variables were tested for normality using the Shapiro–Wilk test and described as mean $\pm$ standard deviation (SD) or median with interquartile range (IQR), as appropriate. Categorical variables were presented as frequencies and percentages.

Missing data were handled using multiple imputation, with the *mice* package (version 3.18.0) in R used to generate imputed datasets and establish the imputation model.

Univariate analyses were conducted to explore associations between potential predictors and PPH. Continuous variables were compared using Student's t-test or Mann–Whitney U test, and categorical variables were compared using the Chi-square test or Fisher's exact test, as appropriate.

Variables with $P < 0.10$ in univariate analysis and clinically relevant factors were included in a multivariable logistic regression model to identify independent risk factors for PPH. The final predictive model was constructed using stepwise backward selection based on the Akaike information criterion (AIC).

Model performance was evaluated using the following metrics:

- Calibration: Model calibration was evaluated using calibration plots and the Hosmer–Lemeshow goodness-of-fit test, implemented in the *rms* package (version 8.1-0). Predicted probabilities were divided into deciles, and observed event rates were compared with the corresponding predicted probabilities. A *P*-value greater than 0.05 indicated a good model fit. Internal validation was conducted using bootstrap resampling (1000 repetitions) to obtain optimism-corrected calibration curves, which evaluated the agreement between predicted and observed risks.
- Discrimination: Discrimination was assessed using the ROC, and the AUC was calculated with the *pROC* package (version 1.19.0.1).
- Clinical utility: the clinical net benefit of the model across a range of threshold probabilities was examined using DCA with the *rmda* package (version 1.6).

A two-tailed $P < 0.05$ was considered statistically significant. All analyses and figures were generated using R software.

3. Results

3.1. Basic information of overall patients

A total of 540 pregnant women were included in this study. The baseline and clinical characteristics of the patient group are summarized in Tables 1 and 3, respectively.

Two groups showed no significant difference in terms of admission route, admission time, and menstrual regularity ($P > 0.05$). However, the proportion of women aged ≥ 35 years in the PPH group was significantly higher than that in the non-PPH group (27.04% vs. 19.26%, $P = 0.041$), suggesting that advanced age may increase the risk of PPH. The obstetric history also showed statistical differences: primiparas accounted for a higher proportion in the PPH group (60.74% vs. 49.63%, $P = 0.012$), while multiparas had a relatively lower proportion. In terms of the method of conception, the proportion of pregnant women using assisted reproductive technology (ART) in the PPH group was significantly higher than that in the non-PPH group (12.59% vs. 4.81%, $P = 0.002$), suggesting that ART may be associated with the risk of PPH. There was also a significant difference in the gestational age: preterm pregnancy was more common in the PPH group (19.26% vs. 10%, $P = 0.003$). There was no significant difference in the number of fetuses and mode of delivery between the two groups ($P > 0.05$). Notably, vaginal delivery accounted for 45.93% in the PPH group, while cesarean section accounted for 54.07%, showing that the proportion of cesarean section was slightly lower than that in the non-PPH group, but the difference did not reach statistical significance ($P = 0.164$).

Table 1
Baseline characteristics of categorical variables in the PPH study cohort and non-PPH control group.

Variable	Category	No-PPH (270)	PPH (270)	P -value	Testing method	X- squared	df
Admission route	Outpatient department, n(%)	201(74.44%)	188(69.63%)	0.4536	fisher	2.718	3
	Emergency department, n(%)	64(23, 70%)	73(27.04%)				
	Referral, n(%)	0(0%)	1(0.37%)				
	Others, n(%)	5(1.85%)	8(2.96%)				
Admission time	Daytime, n(%)	188(69.63%)	194(71.85%)	0.6363	Chi- square	0.22367	1
	Night time, n(%)	82(30.37%)	76(28.15%)				
Advanced maternal age (AMA)	≥ 35, n(%)	52(19.26%)	73(27.04%)	0.0413*	Chi- square	4.1639	1
	< 35, n(%)	218(80.74%)	197(72.96%)				
Menstrual regularity	yes, n(%)	232(85.93%)	231(85.56%)	1	Chi- square	0	1
	no, n(%)	38(14.07%)	39(14.44%)				
Fetal number	Single tire, n(%)	263(97.41%)	255(94.44%)	0.1441	fisher	3.9236	2
	Twins, n(%)	7(2.59%)	13(4.82%)				
	Three or more fetuses, n(%)	0(0%)	2(0.74%)				
Pregnancy and childbirth history	Primiparity, n(%)	134(49.63%)	164(60.74%)	0.01209*	Chi- square	6.2974	1
	Delivery, n(%)	136(50.37%)	106(39.26%)		Chi- square		
Mode of conception	Natural conception, n(%)	257(95.19%)	236(87.41%)	0.002264**	Chi- square	9.322	1
	ART, n(%)	13(4.81%)	34(12.59%)				
Delivery time	Daytime, n(%)	173(64.07%)	155(57.41%)	0.1341	Chi- square	2.2443,	1

Variable	Category	No-PPH (270)	PPH (270)	<i>P</i> -value	Testing method	X- squared	df
	Night time, n(%)	97(35.93%)	115(42.59%)				
Is it full term	no, n(%)	27(10%)	52(19.26%)	0.003473**	Chi- square	8.5406	1
	yes, n(%)	243(90%)	218(80.75%)				
Mode of delivery	Delivery through the vagina, n(%)	107(39.63%)	124(45.93%)	0.164	Chi- square	1.9367	1
	Cesarean section delivery, n(%)	163(60.37%)	146(54.07%)				

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

The normality test for continuous variables was conducted using the Shapiro-Wilk method, with $\alpha = 0.05$. The results showed that the variables (such as age, BMI) did not follow a normal distribution ($P < 0.05$), and non-parametric test methods were used in subsequent analyses, as detailed in Table 2.

Table 2
Normality test of continuous variables.

Variable	Shapiro-Wilk W	P-value	Whether it is a normal distribution
Blood loss amount	0.82038	< 2.2e-16	no
Age	0.98393	1.129e-05	no
Height	0.99023	0.00119	no
Weight	0.98794	0.000196	no
BMI	0.99384	0.02707	no
Menstrual cycle	0.65999	< 2.2e-16	no
Menstrual period	0.91048	< 2.2e-16	no
Admission gestational week	0.82085	< 2.2e-16	no
Gravida (G)	0.80503	< 2.2e-16	no
Pare (P)	0.71201	< 2.2e-16	no
Abortus (A)	0.67608	< 2.2e-16	no
Living (L)	0.71157	< 2.2e-16	no
Delivery gestational week	0.83936	< 2.2e-16	no
Birth weight	0.95148	2.539e-12	no
Apgar-1min	0.45465	< 2.2e-16	no
Apgar-5min	0.24381	< 2.2e-16	no
Apgar-10min	0.22021	< 2.2e-16	no

For basic demographic indicators, including height, weight, BMI, and gestational age at admission, there were no significant differences between the two groups ($P > 0.05$), suggesting that these factors are not significantly associated with the occurrence of PPH in this cohort. In terms of menstrual-related characteristics, there was no significant difference in menstrual cycle length between the two groups ($P = 0.868$), but the menstrual duration in the PPH group was slightly longer (median 6 days vs. 5 days, $P = 0.024$), indicating that menstrual duration may be somewhat correlated with PPH. The analysis of pregnancy and childbirth history showed that the number of pregnancies (G) was not significantly different between the two groups ($P = 0.953$), but the number of full-term deliveries (P), the number of abortions (A), and the number of live births (L) were all significantly lower in the PPH group than in the non-PPH group (P: 0 vs. 1, $P = 0.015$; A: 0 vs. 0, $P = 0.039$; L: 0 vs. 0.5, $P = 0.030$), suggesting that women with less childbirth experience are more prone to PPH. Other factors, such as gestational age at delivery, birth weight, and Apgar scores (1, 5, 10 minutes), showed no significant differences between the two

groups ($P > 0.05$), indicating that these factors were not significantly associated with the occurrence of PPH in this study.

Table 3
Baseline characteristics of continuous variables in the PPH study cohort and non-PPH control group.

Variable	Category	No-PPH (270)	PPH (270)	P-value	Testing method
Blood loss amount	Median(IQR)	299.5 (200, 300)	1250 (1060, 1560)	< 2.2e-16***	Mann–Whitney U test
Basic information	Maternal age, median(IQR)	32 (28, 34)	32 (29, 35)	0.2408	Mann–Whitney U test
	Height, median(IQR)	163 (160, 166)	163 (160, 166)	0.9096	Mann–Whitney U test
	Weight, median(IQR)	74 (67.125, 80)	75 (69, 82.575)	0.09886	Mann–Whitney U test
	BMI, median(IQR)	27.72(25.61, 30.11)	28.27(25.86, 30.86)	0.07328	Mann–Whitney U test
	Admission gestational week, median(IQR)	272 (266, 279)	273 (260.25, 280)	0.8826	Mann–Whitney U test
Menstruation	Menstrual cycle, median(IQR)	29 (28, 30)	30 (28, 30)	0.8678	Mann–Whitney U test
	Menstrual period, median(IQR)	5 (4, 6.75)	6 (5, 7)	0.02402*	Mann–Whitney U test
Pregnancy and childbirth history	G, median(IQR)	2 (1, 3)	2 (1, 3)	0.9532	Mann–Whitney U test
	P, median(IQR)	1 (0, 1)	0 (0, 1)	0.01498*	Mann–Whitney U test
	A, median(IQR)	0 (0, 1)	0 (0, 1)	0.03937*	Mann–Whitney U test
	L, median(IQR)	0.5 (0, 1)	0 (0, 1)	0.02993*	Mann–Whitney U test
Delivery gestational week	Days, median(IQR)	273 (267, 280)	274.5 (262, 281)	0.8182	Mann–Whitney U test

Variable	Category	No-PPH (270)	PPH (270)	P-value	Testing method
Fetus	Birth weight, median(IQR)	3330 (3042.5, 3647.5)	3415 (2922.5, 3760)	0.2138	Mann– Whitney U test
	1min, median(IQR)	10 (9, 10)	10 (10, 10)	0.253	Mann– Whitney U test
	5min, median(IQR)	10 (10, 10)	10 (10, 10)	0.1162	Mann– Whitney U test
	10min, median(IQR)	10 (10, 10)	10 (10, 10)	0.4945	Mann– Whitney U test

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

3.2. PPH's univariate Logistic regression

A univariate Logistic regression analysis was conducted on each potential predictive factor, and the results are shown in *Appendix A.1* and Table 4. The results showed that advanced age (≥ 35 years) was significantly associated with the risk of postpartum hemorrhage (OR = 1.55, 95% CI 1.04–2.34, $P = 0.0328$). Primiparous women (OR = 1.57, 95% CI 1.12–2.21, $P = 0.0096$), assisted reproductive pregnancy (OR = 2.85, 95% CI 1.50–5.72, $P = 0.0020$), and preterm birth (OR = 2.15, 95% CI 1.31–3.58, $P = 0.0027$) all significantly increased the risk of postpartum hemorrhage. BMI, menstrual period, P, placenta previa or low-lying placenta (OR = 6.49, 95% CI 2.46–22.31, $P < 0.001$), and known or suspected placenta accreta disease (OR = 12.51, 95% CI 2.44–228.76, $P = 0.0155$) all showed significant or potential correlations. In addition, PLT, APTT, and Fib were negatively correlated with postpartum hemorrhage, while higher LDL levels showed a trend towards increased risk ($P = 0.0557$). Other variables such as age, weight, placental abruption, or active bleeding did not reach statistical significance.

Table 4
Univariate logistic regression analysis of the risk factors for PPH.

Variable	OR	95% CI	P-value
AMA	1.55	1.04–2.34	0.0328 *
Age (Continuous)	1.03	0.99–1.07	0.0942
Weight (Continuous)	1.01	1.00–1.03	0.0872
Primiparous woman	1.57	1.12–2.21	0.0096 **
Method of Conception (ART vs. Natural Conception)	2.85	1.50–5.72	0.0020 **
Weeks of pregnancy (premature vs full-term)	2.15	1.31–3.58	0.0027 **
BMI	1.05	1.00–1.10	0.0344 *
Duration of menstrual period (Continuous)	1.14	1.01–1.29	0.0397 *
P (Continuous)	0.76	0.58–0.99	0.0438 *
L (Continuous)	0.78	0.59–1.02	0.076
Placenta previa or low-lying placenta	6.49	2.46–22.31	0.000631 ***
Known or suspected placenta accreta disease	12.51	2.44–228.76	0.0155 *
Placental abruption or active bleeding	3.42	1.03–15.39	0.0639
PLT	0.995	0.992–0.999	0.00795 **
APTT	0.927	0.883–0.971	0.00180 **
Fib	0.769	0.622–0.927	0.0117 *
LDL	1.82	0.712–1.003	0.0557

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

3.3. PPH's multivariate Logistic regressions:

Based on the results of univariate analysis and univariate logistic regression, variables with $P < 0.1$ were included in multivariate logistic regression analysis. Multivariate logistic regression analysis showed that AMA, primiparity, ART, placenta previa or low-lying placenta, higher BMI, and longer menstrual periods were independent risk factors for PPH, while multiparity, elevated platelets, and shortened APTT were protective factors (Table 5). The specific results were as follows: AMA OR = 2.05 (95% CI 1.28–3.28, $P = 0.003$); primiparity OR = 0.48 (95% CI 0.32–0.71, $P < 0.001$); ART OR = 2.28 (95% CI 1.11–4.66, $P = 0.024$); placenta previa or low-lying placenta OR = 5.96 (95% CI 1.87–18.96, $P = 0.002$); BMI OR = 1.06 (95% CI 1.01–1.11, $P = 0.027$); duration of menstrual period OR = 1.17 (95% CI 1.02–1.34, $P = 0.026$); platelet OR = 0.996 (95% CI 0.993–0.999, $P = 0.012$); APTT OR = 0.92 (95% CI 0.88–0.97, $P = 0.001$). Full-term

pregnancy and fibrinogen levels had a trend toward protective effects on PPH, but did not reach statistical significance.

Table 5
Multivariable logistic regression analysis of the risk factors for PPH

Variable	β (Estimate)	Std. Error	z value	P- value	OR	95% Confidence Interval (Estimation)
Intercept	2.035	1.326	1.535	0.125	—	—
AMA	0.719	0.246	2.923	0.003**	2.05	1.28–3.28
Delivery	-0.736	0.208	-3.540	0.0004***	0.48	0.32–0.71
Assisted reproductive pregnancy	0.824	0.366	2.252	0.024*	2.28	1.11–4.66
Full-term pregnancy	-0.521	0.294	-1.773	0.076	0.59	0.33–1.06
BMI	0.059	0.027	2.207	0.027*	1.06	1.01–1.11
Duration of menstrual period	0.156	0.070	2.231	0.026*	1.17	1.02–1.34
Placenta previa or low-lying placenta	1.784	0.587	3.040	0.002**	5.96	1.87–18.96
PLT	-0.00464	0.00184	-2.513	0.012*	0.996	0.993–0.999
APTT	-0.0828	0.0259	-3.196	0.001**	0.92	0.88–0.97
Fib	-0.171	0.093	-1.833	0.067	0.84	0.69–1.02

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Multicollinearity among predictors in the multivariable logistic regression model was assessed using the generalized variance inflation factor (GVIF, Table 6). All variables exhibited $GVIF^{(1/(2 \cdot Df))}$ values below 1.2, with the highest value being 1.116 for delivery, indicating low correlation among predictors and no significant multicollinearity. Therefore, the regression coefficients are considered stable and reliable.

Table 6
Multiple collinearity between predictive variables.

Variable	GVIF	Degree of freedom (Df)	GVIF ^{1/(2*Df)}
Placenta previa or low-lying placenta	1.082	1	1.041
APTT	1.035	1	1.017
ART	1.023	1	1.011
Fib	1.022	1	1.011
Delivery	1.245	1	1.116
AMA	1.221	1	1.105
PLT	1.031	1	1.015
BMI	1.031	1	1.015
Duration of menstrual period	1.045	1	1.022
Full-term pregnancy	1.110	1	1.053

3.4. Construction and verification of the PPH prediction mode.

$Y = \text{Logit}(P) = 2.0347 + 0.7187*(AMA) - 0.7357*(Delivery) + 0.8241*(ART) - 0.5211*(Full-term) + 0.0591*BMI + 0.1556*(Duration\ of\ menstrual\ period) + 1.7845*(Placenta\ previa\ or\ low-lying\ placenta) - 0.0046*(PLT) - 0.0828*(APTT) - 0.1712*(Fib)$. When $P > 0.021$, the model predicts that PPH will occur.

Table 7
Explanation of variables included in the regression model.

Variable	Value Description
AMA	≥ 35 years = 1; <35 years = 0
Delivery	Delivery = 1; Primiparity = 0
ART	yes = 1; no = 0
Full-term pregnancy	Full-term pregnancy = 1; Premature birth = 0
Placenta previa or low-lying placenta	yes = 1; no = 0
BMI	kg/m ² , Continuous variable
Duration of menstrual period	Days, Continuous variable
PLT	$\times 10^9/L$, Continuous variable
APTT	s, Continuous variable
Fib	g/L, Continuous variable

The Hosmer-Lemeshow goodness-of-fit test results show: $X^2 = 10.053$, degrees of freedom = 8, $P = 0.2613$. The results indicate that there is no significant difference between the predicted probabilities of the model and the actual observed event rates, suggesting that the logistic regression model fits well in the data of this study.

To assess the robustness of the predictive model, internal validation was performed using the bootstrap method (Bootstrap, $B = 1000$). The results show that the model's discriminative ability is moderately above average (adjusted Somers' Dxy = 0.418, $R^2=0.126$), the intercept is close to zero (-0.0082), the calibration slope is slightly below 1 (0.816), indicating that the predicted values are slightly overestimated, but overall calibration is good. Other indicators ($E_{max} = 0.047$, $U = 0.0092$) further support that the model's predictions are well matched with the actual observed values. The calibration curve shows that the mean absolute error is 0.032, the mean squared error is 0.00146, 90% of the sample absolute errors are ≤ 0.05 , and the predicted probabilities are highly consistent with the actual probabilities (Fig. 2). In summary, the model has good discriminative ability and calibration performance and can be used for predicting postpartum hemorrhage risk.

To evaluate the predictive model's ability to differentiate between high-risk and low-risk patients with postpartum hemorrhage, ROC analysis was conducted (Fig. 3). The results showed that the AUC of the model was 0.729 (95% CI: 0.686–0.772), indicating that the model has a moderate-to-high discriminative ability. The optimal prediction threshold determined by the Youden index was 0.545, corresponding to a sensitivity of 57.78% and a specificity of 81.11%. These results suggest that the model can differentiate high-risk and low-risk patients well, but there is still a risk of missed diagnosis in identifying some high-risk patients. Overall, the model has certain application value in clinical risk assessment of postpartum hemorrhage.

The practical value of the DCA evaluation model in clinical risk decision-making is demonstrated (Fig. 4). The results show that when the threshold probability is approximately 0.2–0.6, the net benefit of the model is significantly higher than that of the "full intervention" or "no intervention" strategies, suggesting that using the model for postpartum hemorrhage risk assessment within this range can bring additional clinical benefits. When the threshold is too low or too high, the net benefit of the model is close to the reference line, indicating that the decision-making value of the model is limited under extreme thresholds. Overall, the model has certain clinical application value within a reasonable threshold range.

4. Discussion

PPH is the leading cause of maternal morbidity and death worldwide. According to the WHO, it accounts for more than 20% of all maternal deaths. Although the mortality rate of PPH has decreased significantly in high-income countries through improved health care systems and interventions, the challenge remains severe in low- and middle-income countries. Therefore, early and accurate identification of PPH high-risk groups and targeted prevention and intervention are the key to reducing maternal adverse outcomes and improving maternal and infant health.

Traditional postpartum hemorrhage risk assessment methods, such as risk assessment tables recommended in some clinical guidelines, usually take the form of a "risk checklist" or "scoring system." Although these tools are simple and easy to use, their AUC may have certain limitations. The academic community is gradually shifting the focus of research to quantitative prediction models constructed based on advanced methods such as multivariate statistical analysis and machine learning, in order to achieve more precise risk stratification[18]. This study aims to systematically identify independent risk factors and protective factors associated with postpartum hemorrhage through multifactor logistic regression analysis and to provide a solid data foundation for the construction of its predictive model, in the context of the aforementioned research.

The core findings of this study are that AMA, primiparity, ART, placenta previa or low-lying placenta, higher BMI, and longer duration of menstrual period are all independent risk factors for postpartum hemorrhage. At the same time, multiparity, higher platelet count, and shorter APTT are considered independent protective factors. These findings not only align with the general understanding in existing medical literature but also reveal some novel associations worth further exploration, providing a more comprehensive perspective for the prediction and prevention of postpartum hemorrhage.

4.1. AMA

PPH in elderly primiparas is significantly higher than that in primiparas of appropriate age ($OR = 2.05$, $P = 0.003$), consistent with multiple domestic and international research findings[19]. The biological basis of this correlation may be related to the physiological changes that occur in the uterus with age: as age increases, the proportion of fibrous tissue in the uterine muscle layer increases, and the relative number of effective smooth muscle cells decreases, leading to difficulty in producing sufficient and sustained contraction force after the fetus is delivered, thus making it prone to uterine atony. Uterine atony is the most common cause of postpartum hemorrhage, accounting for about 70% of most PPH cases[11, 20]. In addition, advanced maternal age often accompanies pathological conditions such as pregnancy-induced hypertension, gestational diabetes, uterine fibroids, placenta previa, and placenta accreta (PAS); these coexisting factors or complications can independently increase the risk of bleeding and, together with advanced age, contribute to the rising incidence of PPH in this population.

4.2. BMI

This study shows that BMI is significantly associated with PPH ($OR = 1.06$, $P = 0.027$). Previous research results are consistent with this study. Multiple studies have found that compared to women with normal weight, obese women are more likely to have pregnancy complications such as preeclampsia, gestational diabetes mellitus (GDM), macrosomia, antepartum hemorrhage, and preterm delivery[21]. The statistical analysis of different BMI groups further indicates that the incidence of adverse pregnancy outcomes in underweight and overweight/obese mothers is significantly increased. Among them, the incidence of PPH in obese women ($BMI = 30-34.9 \text{ kg/m}^2$) reaches as high as 34.7%[22]. The incidence of PPH can rise to 44.6% in women with extreme obesity ($BMI \geq 40 \text{ kg/m}^2$)[23]. In addition, studies have shown that compared to women with normal weight, overweight women have an increased total bleeding risk ($aOR =$

1.06; 99% CI 1.04–1.08) and uterine atony bleeding risk (aOR = 1.07; 99% CI 1.05–1.09). After vaginal delivery, the probability of bleeding or postpartum hemorrhage in overweight and obese women can increase by about 19%; while after cesarean delivery, the risk of severe bleeding in obese women is relatively reduced by about 14%. It is noteworthy that obesity is also associated with lower uterine cavity pressure during delivery, suggesting that it may lead to uterine atony and secondary postpartum hemorrhage by reducing uterine contraction[24]. In addition, excessive weight gain during pregnancy is also presented as an independent risk factor for PPH (aOR = 1.64, 95% CI 1.08–2.51, $P = 0.021$)[25]. This study and previous evidence both indicate that higher BMI and excessive weight gain during pregnancy are important risk factors for PPH. Reasonable weight management during pregnancy has important clinical significance for reducing the risk of PPH.

4.3. ART

The risk of PPH in women with assisted ART pregnancies is more than double that of women with natural pregnancies. This finding is consistent with the conclusions of multiple large-scale cohort studies and systematic reviews, suggesting that ART pregnancy is an independent risk factor for PPH[26, 27]. However, this correlation does not mean that assisted reproductive technology itself directly leads to PPH, but is more likely to reflect the role of assisted reproductive pregnancy as a "converger" of multiple high-risk factors in epidemiology. With the widespread application of assisted reproductive technology, an increasing number of pregnant women over the age of 35, women with scarred uteruses, and women with multiple internal medical diseases are becoming pregnant through this method, thereby changing the distribution pattern of high-risk factors for PPH[28]. It is worth noting that assisted reproductive pregnancy is closely related to a variety of known PPH high-risk factors, among which the risk increase of pre-placed placenta is the most significant[29]. Multiple studies have confirmed that assisted reproductive technology is an independent risk factor for placenta previa, and placenta previa itself is a highly risky factor leading to PPH. Therefore, the OR of assisted reproductive pregnancy may partially reflect the synergistic effect of accompanying risk factors such as "elderly primigravidas" and "placenta previa."

4.4. Primiparous women

This study identifies primiparous women as an independent risk factor for PPH, while experienced women are identified as a significant protective factor. Primiparous women are more prone to delivery fatigue due to a tighter birth canal and a longer labor process, and excessive fatigue during labor can weaken the uterine contraction after placental detachment, increasing the risk of uterine atony and thus the risk of PPH. Long-term or prolonged labor (especially prolonged first or second stage of labor) has been confirmed to increase the incidence of severe PPH by exhausting the effective contraction of the uterus or extending the third stage of labor[30, 31]. In addition, the risk of damage to the soft birth canal (such as perineal, vaginal, or cervical lacerations) increases with prolonged labor[32]. While perineal laceration itself is an important cause of postpartum hemorrhage, in contrast, multiparous women, after the "exercise" of uterine muscle contraction mechanism during past pregnancy-childbirth process, often have better coordination and efficacy of uterine contractions; after placental detachment, the uterus of

multiparous women can contract more quickly and more strongly, timely compressing the open blood vessels of the placental bed and achieving physiological hemostasis. This mechanism can explain the protective effect of multiparity on PPH statistically.

4.5. Premature birth

This study found a negative correlation trend between term pregnancy and PPH (OR = 0.59, 95% CI 0.33–1.06, $P = 0.076$), suggesting that it may have a certain protective effect, although the results did not reach statistical significance. This trend has biological rationality: during term pregnancy, the uterus and placenta are more maturely developed, the uterine muscle layer contraction and restoration function are relatively perfect, which helps the successful completion of hemostasis after placental detachment. Conversely, in preterm deliveries, the lower segment of the uterus is underdeveloped, and the contractile force of muscle fibers is weak, which easily leads to uterine atony and delayed hemostasis, thereby increasing the risk of hemorrhage[33]. Premature delivery often results in incomplete development of the lower uterine segment and weak muscle fiber contraction, which easily leads to insufficient uterine contractions and delayed hemostasis, thereby increasing the risk of bleeding[34]. Previous studies have also reported that the risk of postpartum hemorrhage in term deliveries is lower than that in preterm deliveries[35, 36] or post-term deliveries[37]. Although the results of this study did not reach a significant level, the trend suggests that gestational maturity may play a potential protective role in preventing excessive bleeding, and further verification and exploration of its potential mechanism are still needed through large-scale, multi-center studies.

4.6. Placenta previa or low-lying placenta

Placenta previa or low-lying placenta is the highest risk factor among all (OR = 5.96, $P = 0.002$), and this finding is highly consistent with existing literature[38, 39]. The high-risk pathophysiological basis lies in the attachment position of the placenta. Normally, the placenta attaches to the body of the uterus, which is rich in muscle fibers and strong in contraction, able to effectively compress the blood vessels after the placenta detaches. However, when there is a low-lying or anterior placenta, the placenta attaches to the lower segment of the uterus, where there are fewer and thinner muscle fibers and weaker contractions. When the placenta detaches from this location, the lower segment of the uterus cannot contract effectively, leading to persistent open blood vessels and causing fatal massive hemorrhage[40]. More seriously, an anterior placenta often accompanies the risk of placenta accreta, a pathological condition where the placenta invades the uterine muscle layer, which often requires hysterectomy to ultimately stop the bleeding[41].

4.7. PLT APTT Fib

This study shows that PLT is negatively correlated with the risk of PPH (OR = 0.996, $P = 0.012$), and APTT is also significantly associated with PPH (OR = 0.92, $P = 0.001$). These results suggest that abnormal coagulation function may play a key role in the occurrence of PPH, especially since thrombocytopenia and abnormal activation of the coagulation pathway may increase the risk of bleeding. This finding is consistent with previous research. Many studies have confirmed that a decrease in PLT count and an

extension of coagulation time indicators (PT, APTT, and TT) are independent risk factors for immediate PPH[42]. In addition, low fibrinogen levels and thrombocytopenia are closely related to the incidence and severity of PPH[43]. In a study on a predictive model for placenta previa pregnancy PPH based on clinical features and coagulation function indicators, PLT, D-dimer, APTT, Fib, and hemoglobin all showed significant predictive value[44]. In addition, women with severe fibrinogen deficiency are at high risk of miscarriage, placental abruption, and postpartum hemorrhage during pregnancy. Congenital afibrinogenemia and hypofibrinogenemia are rare inherited coagulation disorders characterized by a lack or insufficient fibrinogen[45]. Further elaborates on the critical role of coagulation system integrity in maintaining hemostatic balance during pregnancy and childbirth. Some studies have proposed predictive thresholds for coagulation-related indicators, such as $PLT \leq 212 \times 10^9/L$, $PT > 11$ seconds, and $APTT > 28.8$ seconds, but their sensitivity and specificity in immediate PPH prediction are still limited[42]. This study finds that both PLT and APTT are independent protective or risk factors for PPH, providing new evidence for incorporating coagulation function parameters into the early risk prediction model for PPH. Future research can further explore the relationship between platelet function, fibrinogen levels, and coagulation factor activity with the severity of PPH and the timing of intervention, thereby optimizing the construction of the multi-parameter prediction model and providing a reference for clinical early warning and individualized management.

4.8. Duration of menstruation

This study shows that the duration of menstrual periods is also significantly associated with PPH (OR = 1.17, $P = 0.026$), suggesting that past menstrual performance may reflect bleeding tendencies or physiological characteristics related to postpartum hemorrhage. Previous studies have indicated that heavy menstrual bleeding often coexists with heavy postpartum bleeding, and both may be related to coagulation dysfunction or bleeding disorders[46, 47]. However, previous research on menstrual characteristics has mainly focused on the period after PPH, using menstrual volume or cycle as indicators to assess the recovery of patients' gynecological and reproductive functions[48, 49]. There are fewer studies that incorporate prenatal menstrual cycle characteristics into the PPH risk prediction model before the perinatal period for evaluation. Based on the results of this study, it is recommended that future research further explore the independent predictive value and potential mechanisms of menstrual history (such as menstrual duration and menorrhagia) in PPH risk assessment, in order to provide additional evidence for clinical screening and prevention.

4.9. Advantages and limitations

This study has several advantages, including a sufficient patient sample size and a comprehensive evaluation of variables including patient demographic characteristics, delivery-related features, and prenatal laboratory indicators such as blood routine, coagulation, and blood lipids, which to some extent improve the reliability of the research results.

However, there are also certain limitations. Firstly, as a two-center retrospective cohort study, there may be differences in patient populations and medical conditions across different regions and hospitals, which may affect the generalizability of the research results. Secondly, the sample size is relatively

limited. Future studies may consider integrating multi-center data to verify the research results and enhance their external applicability.

5. Conclusions

In summary, this study confirms multiple identifiable independent risk factors and protective factors for PPH, providing a scientific basis for clinical prenatal assessment and individualized management. For elderly primiparas, nulliparas, assisted reproductive pregnancy, and those with placental abnormalities, it is necessary to strengthen prenatal screening, formulate reasonable delivery plans, and take active preventive hemostatic measures to reduce the risk of PPH.

Abbreviations

PPH	Postpartum hemorrhage
ROC	Receiver operating characteristic
AUC	Area under the curve
DCA	Decision curve analysis
APTT	Activated partial thromboplastin time
WHO	World Health Organization
HICs	High-income countries
LMICs	Low- and middle-income countries
ACOG	American College of Obstetricians and Gynecologists
BMI	Body mass index
Hct	Hematocrit
Hb	Hemoglobin
PROM	Premature rupture of membranes
WBC	White blood cell
RBC	Red blood cell
PLT	Platelet
FDP	Fibrin degradation product
PT	Prothrombin time
INR	International normalized ratio
Fib	Fibrinogen
ALT	Alanine aminotransferase
AST	Aspartate aminotransferase
HDL	High-density lipoprotein
LDL	Low-density lipoprotein
sdLDL	Small dense low-density lipoprotein
LDH	Lactate dehydrogenase
SD	Standard deviation
IQR	Interquartile range
AIC	Akaike information criterion

ART	Assisted reproductive technology
AMA	Advanced maternal age
G	Gravida
P	Para
A	Abortus
L	Living
GVIF	Generalized variance inflation factor
PAS	Placenta accreta
GDM	Gestational diabetes mellitus

Declarations

Institutional Review Board Statement: The study was conducted in accordance with the Helsinki Declaration and approved by the Ethics Committee of Shandong Provincial Hospital (Approval No.: SWYX: NO.2021 – 532).

Conflicts of Interest:

No financial or non-financial benefits have been received or will be received from any party related directly or indirectly to the subject of this article.

Informed Consent Statement

The Ethics Committee of Shandong Provincial Hospital abandoned the requirement of written informed consent due to retrospective design.

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Author Contribution

All authors participated in the conceptualization and design of the research. Lan Zhang and Pengzheng Chen contributed to the conceptual design, research selection and data extraction, data analysis, and visualization of charts and tables. Lan Zhang wrote the paper. Pengzheng Chen and Xietong Wang edited

and revised the paper. Pengzheng Chen and Xietong Wang provided financial support. All authors agreed to submit. All authors have read and agreed to the published version of the manuscript.

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Data Availability

Due to the personal privacy of participating in the research, the data in this article cannot be shared publicly. According to reasonable requirements, the data will be shared with the corresponding author.

References

1. GBD 2015 Maternal Mortality Collaborators Global, Regional, and National Levels of Maternal Mortality. 1990–2015: A Systematic Analysis for the Global Burden of Disease Study 2015. *Lancet Lond. Engl.* **388**, 1775–1812. 10.1016/S0140-6736(16)31470-2 (2016).
2. Say, L. et al. Global Causes of Maternal Death: A WHO Systematic Analysis. *Lancet Glob Health.* **2**, e323–333. 10.1016/S2214-109X(14)70227-X (2014).
3. Mammoliti, K. M. et al. When Are Postpartum Haemorrhages Diagnosed? A Nested Observational Study within the E-MOTIVE Cluster-Randomised Trial. *Lancet Glob Health.* **13**, e1946–e1954. 10.1016/S2214-109X(25)00302-X (2025).
4. Sheldon, W. R. et al. Management, Risks, and Maternal Outcomes: Findings from the World Health Organization Multicountry Survey on Maternal and Newborn Health. *BJOG Int. J. Obstet. Gynaecol.* **121** (Suppl 1), 5–13. 10.1111/1471-0528.12636 (2014).
5. Say, L. et al. Global Causes of Maternal Death: A WHO Systematic Analysis. *Lancet Glob Health.* **2**, e323–333. 10.1016/S2214-109X(14)70227-X (2014).
6. Ladfors, L. V., Muraca, G. M., Zetterqvist, J., Butwick, A. J. & Stephansson, O. Postpartum Haemorrhage Trends in Sweden Using the Robson Ten Group Classification System: A Population-Based Cohort Study. *BJOG Int. J. Obstet. Gynaecol.* **129**, 562–571. 10.1111/1471-0528.16931 (2022).
7. Mehrabadi, A. et al. Epidemiological Investigation of a Temporal Increase in Atonic Postpartum Haemorrhage: A Population-Based Retrospective Cohort Study. *BJOG Int. J. Obstet. Gynaecol.* **120**, 853–862. 10.1111/1471-0528.12149 (2013).
8. Lalonde, A. International Federation of Gynecology and Obstetrics Prevention and Treatment of Postpartum Hemorrhage in Low-Resource Settings. *Int. J. Gynaecol. Obstet. Off Organ. Int. Fed. Gynaecol. Obstet.* **117**, 108–118. 10.1016/j.ijgo.2012.03.001 (2012).
9. Practice Bulletin No. 162: Prenatal Diagnostic Testing for Genetic Disorders. *Obstet. Gynecol.* **127**, e108–e122. 10.1097/AOG.0000000000001405 (2016).

10. Creanga, A. A. et al. Maternal Mortality and Morbidity in the United States: Where Are We Now? *J. Womens Health*. **23**, 3–9. 10.1089/jwh.2013.4617 (2014).
11. Committee on Practice Bulletins-Obstetrics Practice Bulletin No. 183: Postpartum Hemorrhage. *Obstet. Gynecol.* **130**, e168–e186, (2017). 10.1097/AOG.0000000000002351
12. Wormer, K. C., Jamil, R. T. & Bryant, S. B. Postpartum Hemorrhage. In *StatPearls*; StatPearls Publishing: Treasure Island (FL), (2025).
13. Nyfløt, L. T. et al. Risk Factors for Severe Postpartum Hemorrhage: A Case-Control Study. *BMC Pregnancy Childbirth*. **17**, 17. 10.1186/s12884-016-1217-0 (2017).
14. Hosseinzadeh, M., Heshmatkhah, E. & Abtahi, D. Prevalence and Risk Factors of Postpartum Hemorrhage in Cesarean Section: A Retrospective Cohort Study. *J. Obstet. Gynecol. Cancer Res*. **8**, 285–294. 10.30699/jogcr.8.3.285 (2023).
15. Pubu, Z. M. et al. Factors Affecting the Risk of Postpartum Hemorrhage in Pregnant Women in Tibet Health Facilities. *Med. Sci. Monit. Int. Med. J. Exp. Clin. Res*. **27**, e928568. 10.12659/MSM.928568 (2021).
16. Postpartum Hemorrhage - Gynecology and Obstetrics Available online. <https://www.msdmanuals.com/professional/gynecology-and-obstetrics/intrapartum-complications/postpartum-hemorrhage> (accessed on 9 September 2025).
17. Improving Health Care Response to Obstetric Hemorrhage Toolkit. Version 3.0 | California Maternal Quality Care Collaborative Available online: <https://www.cmqcc.org/resource/improving-health-care-response-obstetric-hemorrhage-toolkit-version-30> (accessed on 2 November 2025).
18. Sirichaisit, K., Kaladee, K., Chankong, W. & Romsaiyud, W. Artificial Intelligence Prediction Models for Postpartum Hemorrhage: A Systematic Review and Meta-Analysis. *J. Southeast. Asian Med. Res*. **9**, e0240–e0240. 10.55374/jseamed.v9.240 (2025).
19. Lao, T. T., Sahota, D. S., Cheng, Y. K. Y., Law, L. W. & Leung, T. Y. Advanced Maternal Age and Postpartum Hemorrhage - Risk Factor or Red Herring? *J. Matern -Fetal Neonatal Med. Off J. Eur. Assoc. Perinat. Med. Fed. Asia Ocean. Perinat. Soc. Int. Soc. Perinat. Obstet*. **27**, 243–246. 10.3109/14767058.2013.807240 (2014).
20. Yunas, I. et al. Causes of and Risk Factors for Postpartum Haemorrhage: A Systematic Review and Meta-Analysis. *Lancet Lond. Engl*. **405**, 1468–1480. 10.1016/S0140-6736(25)00448-9 (2025).
21. Ahmed, B. & Konje, J. C. The Epidemiology of Obesity in Reproduction. *Best Pract. Res. Clin. Obstet. Gynaecol*. **89**, 102342. 10.1016/j.bpobgyn.2023.102342 (2023).
22. Naik, R., Karmali, D., Nagarsenkar, A., Mainath, S. & Pednekar, G. Effect of Pre-Pregnancy Maternal Body Mass Index on Obstetric Outcomes in a Tertiary Care Hospital in Goa, India. *J. Obstet. Gynaecol. India*. **72**, 141–146. 10.1007/s13224-021-01565-z (2022).
23. Wastnedge, E. A. N., Fretwell, J., Johns, E. C., Denison, F. C. & Reynolds, R. M. First and Second Pregnancy Outcomes in Women with Class III Obesity: An Observational Cohort Study. *Obes. Res. Clin. Pract*. **15**, 357–361. 10.1016/j.orcp.2021.05.004 (2021).

24. Butwick, A. J. et al. Effect of Maternal Body Mass Index on Postpartum Hemorrhage. *Anesthesiology* **128**, 774–783. 10.1097/ALN.0000000000002082 (2018).
25. Chawanpaiboon, S. & Lucksanapanij, M. Impact of Maternal Weight and Gestational Weight Gain on Postpartum Hemorrhage and Adverse Outcomes: A Case-Control Study. *Int. J. Womens Health*. **17**, 3567–3575. 10.2147/IJWH.S552037 (2025).
26. Yamamura, A. et al. The Impact of Assisted Reproductive Technology on the Risk of Postpartum Hemorrhage: Difference by the Mode of Delivery and Embryo Transfer. *J. Obstet. Gynaecol. Res.* **49**, 1167–1172. 10.1111/jog.15572 (2023).
27. Tang, D., Cheng, Y., Feng, X., Li, X. & Coyte, P. C. The Use of IVF/ICSI and Risk of Postpartum Hemorrhage: A Retrospective Cohort Study of 153,765 Women in China. *Front. Public. Health*. **11**, 1016457. 10.3389/fpubh.2023.1016457 (2023).
28. Qin, J., Liu, X., Sheng, X., Wang, H. & Gao, S. Assisted Reproductive Technology and the Risk of Pregnancy-Related Complications and Adverse Pregnancy Outcomes in Singleton Pregnancies: A Meta-Analysis of Cohort Studies. *Fertil. Steril.* **105** (.e1-6), 73–85. 10.1016/j.fertnstert.2015.09.007 (2016).
29. Siargkas, A. et al. The Association of Assisted Reproductive Technology with Placental and Umbilical Abnormalities. *J. Pers. Med.* **15**, 176. 10.3390/jpm15050176 (2025).
30. Ende, H. B. et al. Risk Factors for Atonic Postpartum Hemorrhage. *Obstet. Gynecol.* **137**, 305–323. 10.1097/AOG.0000000000004228 (2021).
31. Nyfløt, L. T., Stray-Pedersen, B., Forsén, L. & Vangen, S. Duration of Labor and the Risk of Severe Postpartum Hemorrhage: A Case-Control Study. *PloS One*. **12**, e0175306. 10.1371/journal.pone.0175306 (2017).
32. Risk Factors for Perineal and Vaginal Tears in Primiparous Women – the Prospective POPRACT-Cohort Study. | BMC Pregnancy and Childbirth | Full Text Available online: https://bmcpregnancychildbirth.biomedcentral.com/articles/10.1186/s12884-020-03447-0?utm_source=chatgpt.com (accessed on 25 September 2025).
33. Tattersall, M. et al. Pro-Labour Myometrial Gene Expression: Are Preterm Labour and Term Labour the Same? *Reprod. Camb. Engl.* **135**, 569–579. 10.1530/REP-07-0461 (2008).
34. Phung, J. et al. Preterm Labor Is a Distinct Process from Term Labor Following Computational Analysis of Human Myometrium. *Am. J. Obstet. Gynecol.* **226**, 106e1–106e16. 10.1016/j.ajog.2021.07.002 (2022).
35. N, E. et al. Combined Vaginal Progesterone and Cervical Pessary Effect on Preterm Birth in Singleton Pregnancies with Short Cervix: A Retrospective Cohort Study. *BMC Pregnancy Childbirth*. **25** 10.1186/s12884-025-08255-y (2025).
36. Sheldon, W. R. et al. Management, Risks, and Maternal Outcomes: Findings from the World Health Organization Multicountry Survey on Maternal and Newborn Health. *BJOG Int. J. Obstet. Gynaecol.* **121**, 5–13. 10.1111/1471-0528.12636 (2014).

37. Butwick, A. J. et al. Association of Gestational Age with Postpartum Hemorrhage: An International Cohort Study. *Anesthesiology* **134**, 874–886. 10.1097/ALN.0000000000003730 (2021).
38. Hu, H. et al. Risk Factors of Severe Postpartum Hemorrhage in Pregnant Women with Placenta Previa or Low-Lying Placenta: A Retrospective Cohort Study. *BMC Pregnancy Childbirth*. **24**, 674. 10.1186/s12884-024-06876-3 (2024).
39. DeBolt, C. A. et al. Patients with Resolution of Low-Lying Placenta and Placenta Previa Remain at Increased Risk of Postpartum Hemorrhage. *Ultrasound Obstet. Gynecol. Off J. Int. Soc. Ultrasound Obstet. Gynecol.* **60**, 103–108. 10.1002/uog.24825 (2022).
40. Anderson-Bagga, F. M. & Sze, A. Placenta Previa. In *StatPearls*; StatPearls Publishing: Treasure Island (FL), (2025).
41. Jauniaux, E. et al. A New Methodologic Approach for Clinico-Pathologic Correlations in Invasive Placenta Previa Accreta. *Am. J. Obstet. Gynecol.* **222**, 379e1. 379.e11 (2020).
42. Peng, Y. et al. Evaluating Predelivery Platelet and Coagulation Indices as Predictors of Immediate Postpartum Haemorrhage in Low-Risk Women Undergoing Vaginal Delivery. *BMC Pregnancy Childbirth*. **25**, 298. 10.1186/s12884-025-07427-0 (2025).
43. Anakmeteeprugs, S. et al. Baseline Values for Quantra® QPlus® in Healthy Pregnant Women at Term and Comparison to Standard Laboratory Coagulation Values: A Prospective Observational Study. *BMC Pregnancy Childbirth*. **25**, 826. 10.1186/s12884-025-07927-z (2025).
44. Hong, S. et al. The Development and Validation of Postpartum Hemorrhage Prediction Models for Pregnancies with Placenta Previa Totalis Based on Coagulation Function Indexes: A Retrospective Cohort Study. *BMC Pregnancy Childbirth*. **25**, 925. 10.1186/s12884-025-08066-1 (2025).
45. Casini, A. & de Moerloose, P. Management of Young and Ageing Women with Afibrinogenemia and Hypofibrinogenemia. *Hamostaseologie* **45**, 390–395. 10.1055/a-2568-1255 (2025).
46. Mauser-Bunschoten, E. P. et al. Managing Women-Specific Bleeding in Inherited Bleeding Disorders: A Multidisciplinary Approach. *Haemoph. Off J. World Fed. Hemoph.* **27**, 463–469. 10.1111/hae.14221 (2021).
47. Bank, T. C., Ma'ayeh, M. & Rood, K. M. Maternal Coagulation Disorders and Postpartum Hemorrhage. *Clin. Obstet. Gynecol.* **66**, 384–398. 10.1097/GRF.0000000000000787 (2023).
48. Kaplanoglu, D., Bulbul, M., Kaplanoglu, M. & Dilbaz, B. The Effect of B-Lynch Uterine Compression Suture Performed for Uterine Atony on Future Menstrual Pattern and Reproductive Outcome. *Ginek. Pol.* **95**, 687–692. 10.5603/gpl.92963 (2024).
49. Zhang, X. Q., Chen, X. T., Zhang, Y. T. & Mai, C. X. The Emergent Pelvic Artery Embolization in the Management of Postpartum Hemorrhage: A Systematic Review and Meta-Analysis. *Obstet. Gynecol. Surv.* **76**, 234–244. 10.1097/OGX.0000000000000887 (2021).

Figures

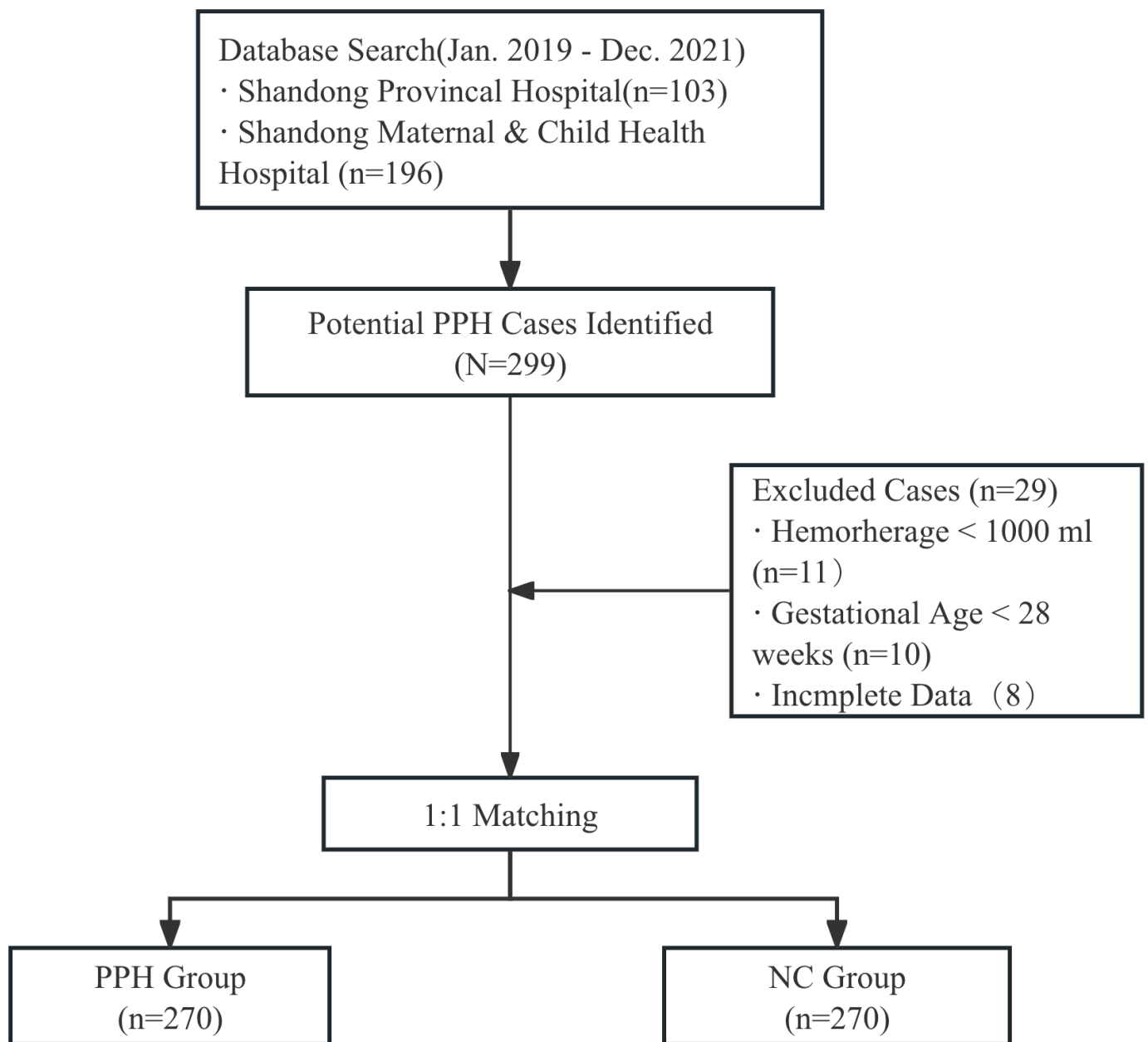


Figure 1

Research flowchart.

Calibration Curve

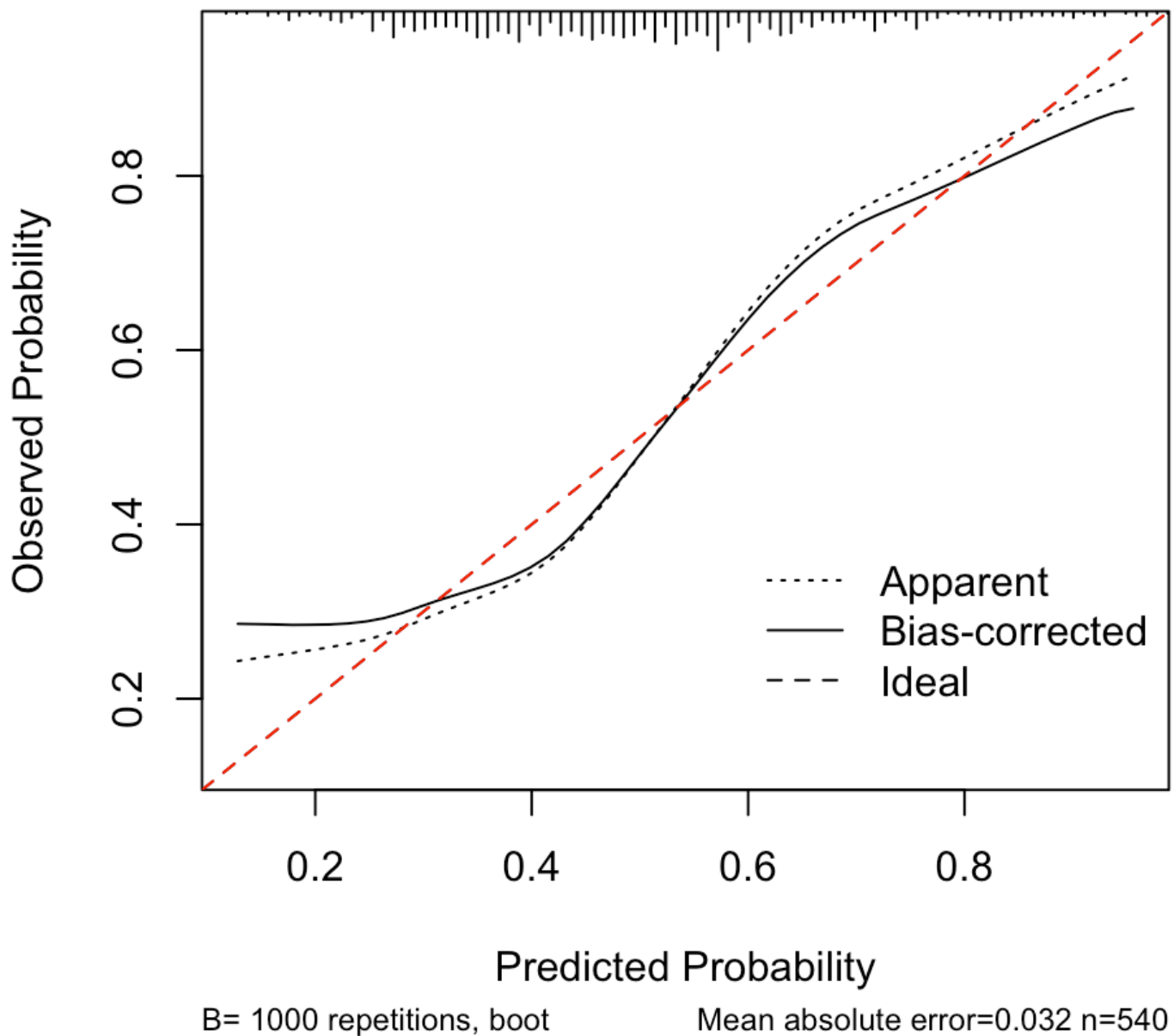


Figure 2

Calibration curve of the logistic regression model with 1,000 bootstrap resamples for internal validation. The horizontal axis represents the probability of event occurrence predicted by the model, and the vertical axis represents the probability of event occurrence observed in reality. The solid line represents the bias-corrected performance of the model, while the dashed line shows the apparent performance. The diagonal line indicates perfect calibration. A curve close to the diagonal indicates good agreement between predicted and observed outcomes.

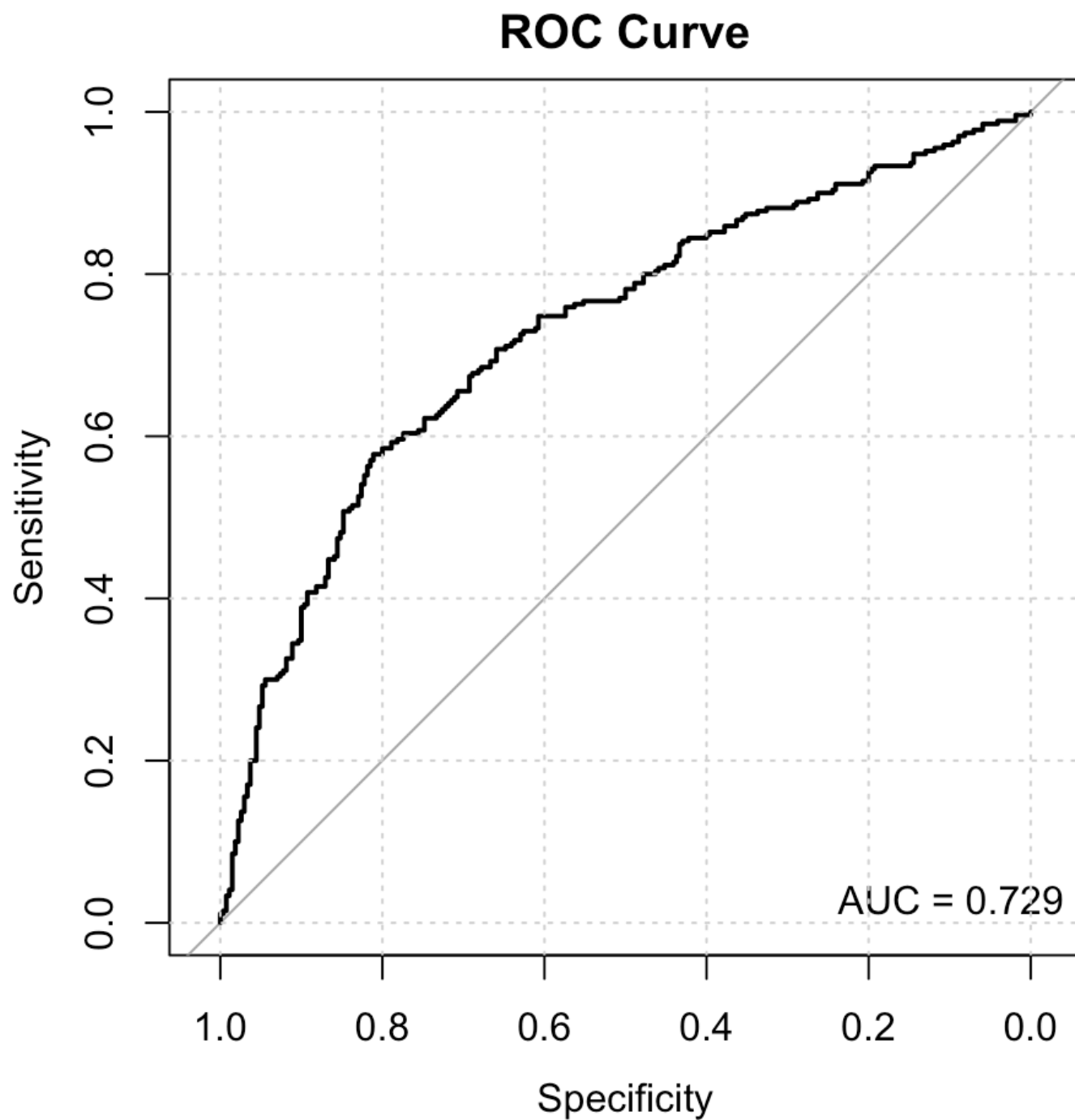


Figure 3

ROC curve of the logistic regression model for predicting postpartum hemorrhage. The AUC demonstrates the discriminative performance of the model, with values closer to 1.0 indicating superior predictive accuracy.

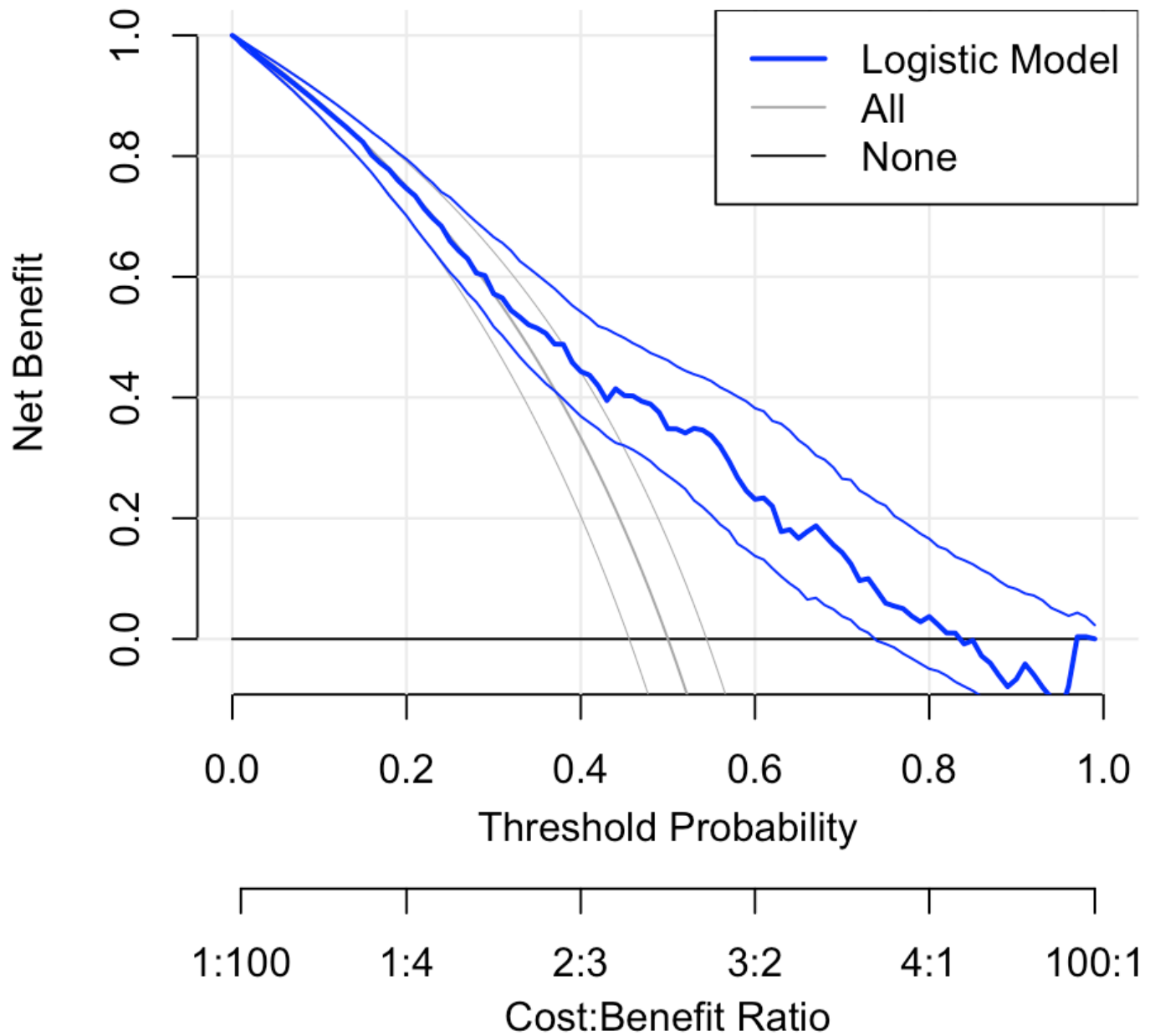


Figure 4

DCA of the predictive model. The net benefit on the y-axis was calculated by adding true positives and subtracting false positives, while the x-axis represents the threshold probability. The curve illustrates the clinical usefulness of the model across a range of threshold probabilities.