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Original Article

Construction of a predictive model for the risk of postpartum hemorrhage in women with advanced maternal age undergoing natural childbirth

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Abstract: Objective: To identify the risk factors of postpartum hemorrhage (PPH) in women of advanced maternal age (AMA) undergoing natural childbirth and to develop a nomogram model for PPH risk prediction in this population. Methods: This study retrospectively collected data from 220 AMA women who had a natural childbirth at the Third Affiliated Hospital of Chengdu Medical College, Chengdu Pidu District People's Hospital between March 2020 and May 2023, forming the training cohort. The cohort was categorized into the PPH group and the non-PPH group based on the occurrence of PPH. Clinical data were compared between the two groups. Univariate and multivariate logistic analyses were employed to identify the factors associated with PPH. A predictive model for the risk of PPH in AMA women was developed, and its predictive accuracy was assessed using calibration curves, receiver operating characteristic (ROC) curves, and decision curve analysis (DCA). Additionally, clinical data from 110 AMA women who had a natural childbirth at our hospital between June 2023 and August 2024 were collected, forming the validation cohort. Results: The overall incidence of PPH was 17.58% (58/330), including 39 from the training cohort, and 19 from the validation cohort. Univariate logistic analysis revealed that age, placenta previa, hypertensive disorder of pregnancy (HDP), fetal macrosomia, uterine atony, and scarred uterus were significant risk factors for PPH in AMA women (all $P < 0.05$). Multivariate logistic model identified age, placenta previa, HDP, uterine atony, and scarred uterus as independent risk factors for PPH in AMA women (all $P < 0.05$). Based on these independent risk factors, a nomogram model for predicting PPH in AMA women was developed, demonstrating an area under the ROC curve (AUC) of 0.841 (95% CI: 0.773-0.908) in the training cohort and 0.868 (95% CI: 0.767-0.969) in the validation cohort. The calibration curve analysis indicated that the model's predicted PPH risk in AMA population closely aligned with the actual outcomes, while DCA demonstrated model's significant clinical utility. Conclusion: The nomogram prediction model developed in this study effectively estimates the risk of PPH in AMA women, offering valuable clinical guidance.

Keywords: Advanced maternal age, postpartum hemorrhage, risk factor, prediction model, nomogram

Introduction

Postpartum hemorrhage (PPH), defined as abnormal vaginal bleeding exceeding 500 mL within 24 h after delivery, is one of the most common complications in obstetrics. If not managed appropriately, it could lead to severe consequence, including disseminated intravascular coagulation (DIC), hemorrhagic shock, and multiorgan failure (MOF), ultimately posing a life-threatening risk to the mother [1]. Statistical data indicates that approximately 25% of global maternal mortalities are associated with PPH [2]. Even among survivors, complications such as puerperal infection, post-transfusion infections, postpartum psychiatric disorders, and Sheehan's syndrome may still arise, significantly affecting their quality of life [3]. Consequently, effective prediction and prevention of PPH have become global priorities in obstetric research.

Advanced maternal age (AMA) is typically defined as pregnancy in women aged 35 years or older. In recent decades, an increasing number of women worldwide have delayed childbearing. In the United States, the proportion of births to women aged 35-39 years and 40-44

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years increased by 5% and 8%, respectively, between 2006-2007 and 2014-2015. By 2015, women aged 35 years or older accounted for 15.7% of all deliveries [4]. In England and Wales, the average age at first childbirth rose from 27.7 years in 1990 to 30.5 years in 2022 [5]. A similar trend has been observed in China [6], where the fertility rate among women aged 35-39 years increased from 10.98% in 2005 to 18.60% in 2015, while the fertility rate among women aged 40-44 years rose from 2.05% to 5.37% over the same period [7]. A recent study in China revealed that the proportion of AMA pregnancies ranged between 10.00% and 20.24% [8, 9].

The risk of pregnancy complications is elevated in AMA women during spontaneous delivery, primarily due to the physiological changes associated with the aging process. These changes include declining ovarian function, decreased vascular function, weakened immune system, and diminished uterine contractility [10]. Such physiological changes render older women more susceptible to pregnancy-related complications, including gestational hypertension, gestational diabetes, and PPH. Additionally, impaired placental function and fetal development further elevate maternal and fetal risks. Studies have shown that advanced age significantly increases the likelihood of PPH and increases the risk of poor prognosis [11]. PPH is considered a multifactorial condition, with most cases being preventable through appropriate clinical management. Effective prevention and mitigation of PPH-related adverse outcomes hinges on the early identification of risk factors and timely screening of high-risk individuals, enabling preventive or therapeutic measures based on risk assessment [12]. However, studies and guidelines vary in defining PPH risk factors. Currently, widely used clinical tools for assessing the risk of PPH include the California Maternity Quality Collaboration (CMQCC), the Women's Health Obstetrics and Neonatal Nurses Association (AWHONN), and the New York Obstetric Bleeding Safety Guide (NYSBOH) [13]. Although these assessment tools incorporate expert opinions and previously identified risk factors, their predictive efficacy is moderate, primarily identifying high-risk obstetric patients undergoing cesarean delivery [13]. Currently, there is a lack of reliable predictive model that accurately screens high-risk AMA women for PPH following natural childbirth.

This study aims to identify the risk factors associated with PPH in AMA women undergoing vaginal delivery and to develop a nomogram-based predictive model for quantifying individual PPH risk. The nomogram serves as a user-friendly risk assessment tool, enabling clinicians to efficiently stratify AMA women based on their PPH risk scores and implement targeted preventive and therapeutic interventions. By facilitating early risk identification and personalized management, this model has the potential to reduce PPH incidence and improve overall maternal and neonatal outcomes.

Materials and methods

General information

Clinical data from 330 cases of AMA women who had a natural childbirth at the Third Affiliated Hospital Affiliated of Chengdu Medical College, Chengdu Pidu District People's Hospital between March 2020 and August 2024 were retrospectively collected. The patients were divided into a training cohort (n=220, March 2020-May 2023) and a validation cohort (n=110, June 2023-August 2024) using a 2:1 ratio (**Figure 1**). This study was approved by the hospital's ethics committee.

Inclusion criteria: (1) age ≥ 35 years old; (2) natural childbirth; (3) regular maternal and fetal examinations during pregnancy with normal results; (4) gestational age at delivery ≥ 28 weeks; (5) singleton pregnancy.

Exclusion criteria: (1) individuals with communication barriers or mental disorders preventing cooperation; (2) incomplete medical records; (3) coexisting hematologic disorders; (4) coexisting dysfunction of other major organ systems; (5) significant bleeding tendency due to tumors or other underlying diseases.

Clinical data collection

The following data were collected from each AMA case: age, marital status, educational background, pre-pregnancy body mass index (BMI), gestational age, number of pregnancies, postpartum bleeding within 24 h, placental status (presence of placenta previa), amniotic fluid condition (presence of contamination), hypertensive disorders of pregnancy (HDP), gestational diabetes mellitus (GDM), uterine fibroids, fetal weight (presence of macrosomia),

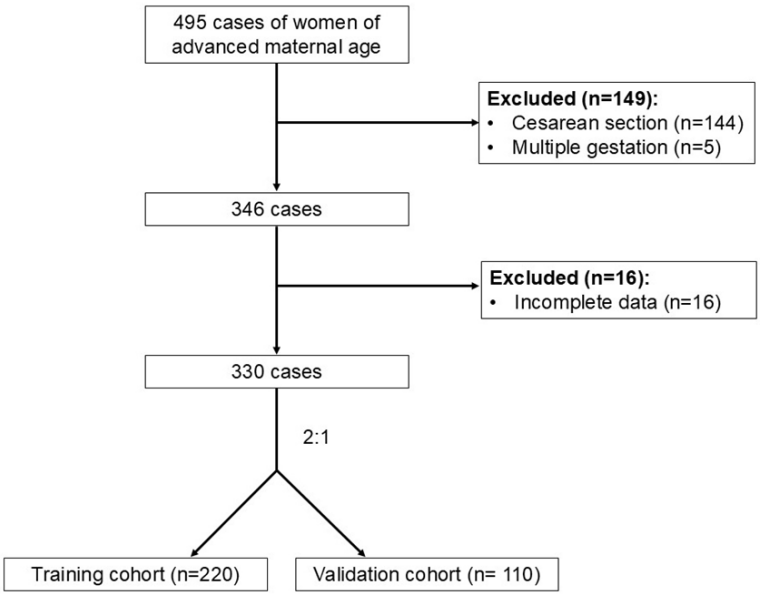

Figure 1. Flow diagram detailing the selection of samples included in this retrospective analysis.

uterine atony, scarred uterus, and the use of assisted reproductive technologies.

Diagnostic criteria for PPH

According to the World Health Organization (WHO), PPH is defined as a cumulative blood loss ≥ 500 mL within 24 h after delivery [14].

Measurement of PPH

Sterile gauze was pre-weighed before use. The gauze was then used to absorb blood during delivery. After absorption, the gauze was re-weighed. Finally, blood loss (mL) was calculated according to the formula: blood loss (mL) = (post-absorption gauze weight (g) - initial gauze weight (g))/1.05 [15].

Statistical analysis

Statistical analyses were conducted using SPSS version 22.0. Kolmogorov-Smirnov normality test was used to assess the normality of data distribution. All continuous variables were normally distributed and presented as mean ± standard ($\bar{x}$ ± sd). The comparison between groups was conducted using the *t*-test. The categorical variables were expressed as percentage and compared by χ^2 test or Fisher's exact tests. Univariate and multivariate logistic analysis were conducted to identify risk factors for PPH in AMA. The nomogram were constructed using R 4.4.0 software. Its diagnostic accuracy and clinical utility were evaluated using calibration curves, receiver operating characteristic (ROC) curves, and decision curve analysis (DCA). A two-sided *P*-value < 0.05 was considered statistically significant.

Results

Incidence of PPH in AMA women

The incidence of PPH among AMA women undergoing natural birth was 17.58% (58/330). In the training cohort, 39 women experienced PPH, while 19 women in the validation cohort developed PPH. Based on the occurrence of PPH, the training cohort was categorized into the PPH group (n=39) and the non-PPH group (n=181), while the validation cohort was similarly categorized into the PPH group (n=19) and the non-PPH group (n=91).

Comparison of clinical data between the training and validation cohort

The comparison of clinical data between the training and validation cohorts revealed no statistically significant differences ($P > 0.05$) (**Table 1**).

Comparison of clinical data between the PPH and non-PPH groups in the training cohort

As shown in **Table 2**, the average age of the PPH group was 40.31±2.53 years, significantly higher than 38.12±2.95 years in the non-PPH group (t=4.300, $P < 0.001$). Besides, significant differences were observed between the two groups in the proportions of placenta previa (χ^2=20.142, $P < 0.001$), HDP (χ^2=7.916, P= 0.005), uterine atony (χ^2=9.615, P=0.002), and scarred uterus (χ^2=17.387, $P < 0.001$).

Univariate logistic analysis of PPH in AMA women

Variable assignments are listed in **Table 3**. A univariate logistic analysis was conducted with PPH as the dependent variable and AMA and

Table 1. Comparison of clinical data between the training and validation cohorts [n (%)]/($\bar{x} \pm sd$)

	Training cohort (n=220)	Validation cohort (n=110)	t/χ^2	*P*
Age	38.51±2.99	38.86±2.64	1.055	0.292
Marital status				
Unmarried	4 (1.82)	3 (2.73)	0.018	0.893
Married	216 (98.18)	107 (97.27)		
Educational background			0.070	0.966
Primary school	25 (11.36)	13 (11.82)		
Middle and high school	65 (29.55)	31 (28.18)		
College	130 (59.09)	66 (60.00)		
Pre-pregnancy BMI (kg/m^2)	22.46±2.50	22.29±2.16	0.196	0.845
Pregnancy BMI (kg/m^2)	27.85±2.96	28.17±2.54	0.969	0.333
Gestational age (week)	38.07±2.21	38.24±2.36	0.637	0.524
Number of Pregnancies			1.210	0.546
1-2 times	165 (75.00)	88 (80.00)		
3-4 times	48 (21.82)	20 (18.18)		
> 4 times	7 (3.18)	2 (1.82)		
Placenta previa			0.140	0.708
No	195 (88.64)	99 (90.00)		
Yes	25 (11.36)	11 (10.00)		
Amniotic fluid contamination			0.050	0.824
No	188 (85.45)	95 (96.36)		
Yes	32 (14.55)	15 (13.64)		
HDP			0.010	0.919
No	181 (82.27)	90 (81.82)		
Yes	39 (17.73)	20 (18.18)		
GDM				
No	185 (84.09)	91 (82.73)	0.100	0.752
Yes	35 (15.91)	19 (17.27)		
Uterine fibroids			0.052	0.819
No	190 (86.36)	96 (87.27)		
Yes	30 (13.64)	14 (12.73)		
Fetal macrosomia			0.087	0.769
No	204 (92.73)	101 (91.82)		
Yes	16 (7.27)	9 (8.18)		
Uterine atony			0.185	0.667
No	155 (70.45)	80 (72.73)		
Yes	65 (29.55)	30 (27.27)		
Scarred uterus			0.202	0.653
No	188 (85.45)	96 (87.27)		
Yes	32 (14.55)	14 (12.73)		
Assisted reproduction			0.191	0.662
No	217 (98.64)	107 (97.27)		
Yes	3 (1.36)	3 (2.73)		

Note: BMI, body mass index; HDP, hypertensive disorder of pregnancy; GDM, gestational diabetes mellitus.

pregnancy related variables as independent variables. The analysis revealed that age (odds ratio [OR]=1.275, 95% confidence interval [95% CI]: 1.130-1.439, $P < 0.001$), placenta

Table 2. Comparison of clinical data between the PPH and non-PPH groups in the training cohort [n (%)]/($\bar{x} \pm sd$)

Variable	PPH (n=39)	Non-PPH (n=181)	t/χ^2	*P*
Age	40.31±2.53	38.12±2.95	4.300	< 0.001
Marital status			0.040	0.842
Unmarried	1 (2.56)	3 (1.66)		
Married	38 (97.44)	178 (98.34)		
Educational background			0.128	0.938
Primary school	4 (10.26)	21 (11.60)		
Middle and high school	11 (28.21)	54 (29.83)		
College	24 (61.54)	106 (58.56)		
Pre-pregnancy BMI (kg/m^2)	22.93±1.47	22.35±2.67	1.313	0.191
Pregnancy BMI (kg/m^2)	27.91±3.04	27.83±2.96	0.150	0.881
Gestational age (week)	38.33±2.06	38.01±2.24	0.820	0.413
Number of Pregnancies			0.913	0.634
1-2 times	30 (76.92)	135 (74.59)		
3-4 times	7 (17.95)	41 (22.65)		
> 4 times	2 (5.13)	5 (2.76)		
Placenta previa			20.142	< 0.001
No	26 (66.67)	169 (93.37)		
Yes	13 (33.33)	12 (6.63)		
Amniotic fluid contamination			0.114	0.736
No	34 (87.18)	154 (85.08)		
Yes	5 (12.82)	27 (14.92)		
HDP			7.916	0.005
No	26 (66.67)	155 (85.64)		
Yes	13 (33.33)	26 (14.36)		
GDM			0.010	0.922
No	33 (84.62)	152 (83.98)		
Yes	6 (15.38)	29 (16.02)		
Uterine fibroids			0.123	0.726
No	33 (84.62)	157 (86.74)		
Yes	6 (15.38)	24 (13.26)		
Fetal macrosomia			3.279	0.070
No	33 (84.62)	171 (94.48)		
Yes	6 (15.38)	10 (5.52)		
Uterine atony			9.615	0.002
No	19 (48.72)	136 (75.14)		
Yes	20 (51.28)	45 (24.86)		
Scarred uterus			17.387	< 0.001
No	25 (64.10)	163 (90.06)		
Yes	14 (35.90)	18 (9.94)		
Assisted reproduction			-	0.445*
No	38 (97.44)	179 (98.90)		
Yes	1 (2.56)	2 (1.10)		

Note: PPH, postpartum hemorrhage; BMI, body mass index; HDP, hypertensive disorder of pregnancy; GDM, gestational diabetes mellitus; *: Fisher's exact tests.

previa (OR=7.042, 95% CI: 2.901-17.090, *P* < 0.001), HDP (OR=2.981, 95% CI: 1.360-6.533, *P*=0.006), fetal macrosomia (OR=3.109, 95% CI: 1.057-9.142, *P*=0.039), uterine atony (OR=

Table 3. Assignment of each factor

Variable	Assignment
Age	Enter the actual value
Pre-pregnancy BMI	Enter the actual value
Pregnancy BMI	Enter the actual value
Gestational age	Enter the actual value
Marital status	0= Unmarried, 1= Married
Educational background	0= Primary school, 1= Middle and high school, 2= College
Number of Pregnancies	0=1-2 times, 1=3-4 times, 2= > 4 times
Placenta previa	0= no, 1= yes
Placenta previa	0= no, 1= yes
HDP	0= no, 1= yes
GDM	0= no, 1= yes
Uterine fibroids	0= no, 1= yes
Fetal macrosomia	0= no, 1= yes
Uterine atony	0= no, 1= yes
Scarred uterus	0= no, 1= yes
Assisted reproduction	0= no, 1= yes

Note: BMI, body mass index; HDP, hypertensive disorder of pregnancy; GDM, gestational diabetes mellitus.

3.181, 95% CI: 1.560-6.488, *P*=0.001), and scarred uterus (OR=5.071, 95% CI: 2.244-11.462, *P* < 0.001) were significant factors associated with PPH in AMA women (**Table 4**).

Multivariate logistic analysis of PPH in AMA women

Variables with *P* value less than 0.05 in univariate analysis were incorporated into the multivariate analysis, and the results identified age (OR=1.302, 95% CI: 1.132-1.499, *P* < 0.001), placenta previa (OR=5.295, 95% CI: 1.891-14.827, *P*=0.002), HDP (OR=3.086, 95% CI: 1.220-7.808, *P*=0.017), uterine atony (OR=2.597, 95% CI: 1.128-5.976, *P*=0.025), and scarred uterus (OR=5.593, 95% CI: 2.094-14.944, *P* < 0.001) as independent risk factors for PPH in AMA women (**Table 5**).

Construction of nomogram prediction model

A nomogram prediction model was developed based on the independent risk factors identified in the multivariate logistic analysis, including age, placenta previa, HDP, uterine atony, and scarred uterus. Each predictor was assigned a score based on its contribution to the outcome variable. The total score was then used to predict the individual risk of PPH in AMA women (**Figure 2**).

Validation of nomogram prediction model

In the training cohort, the area under the ROC curve (AUC) was 0.841 (95% CI: 0.773-0.908), indicating excellent discriminatory performance of the nomogram model (**Figure 3A**). The Hosmer-Lemeshow test confirmed that the model exhibited good fitness and calibration (*P*=0.787) (**Figure 4A**). Decision curve analysis (DCA) revealed that when the threshold probability ranged from 0.05 to 1, the net benefit remained positive, suggesting that the nomogram model holds significant clinical value (**Figure 5A**).

In the validation cohort, the AUC was 0.868 (95% CI: 0.767-0.969), further validating the model's strong discriminatory ability (**Figure 3B**). Hosmer-Lemeshow test also indicated good fit and calibration (*P*=0.178) (**Figure 4B**). DCA analysis showed that when the threshold probability ranged from 0.05 to 0.80, the net benefit remained positive, further supporting the model's clinical applicability (**Figure 5B**). These findings suggest that our nomogram model is a reliable tool for guiding clinical decision-making in assessing PPH risk in AMA women.

Discussion

Postpartum hemorrhage (PPH) is one of the most severe complications of childbirth, posing

Table 4. Univariate logistic analysis of PPH in AMA women

	B	*S.E*	*P*	OR (95% CI)
Age	0.243	0.062	< 0.001	1.275 (1.130-1.439)
Marital status				
Unmarried				Reference
Married	-0.466	1.168	0.703	0.640 (0.065-6.325)
Educational background				
Primary school				Reference
Middle and high school	0.067	0.638	0.916	1.069 (0.306-3.734)
College	0.173	0.591	0.770	1.189 (0.374-3.782)
Pre-pregnancy BMI (kg/m^2)	0.093	0.073	0.198	1.098 (0.952-1.266)
Pregnancy BMI (kg/m^2)	0.050	0.077	0.513	1.052 (0.904-1.223)
Gestational age (week)	-0.066	0.056	0.236	0.936 (0.838-1.044)
Number of Pregnancies				
1-2 times				Reference
3-4 times	-0.264	0.456	0.563	0.768 (0.314-1.878)
> 4 times	0.588	0.861	0.495	1.800 (0.333-9.725)
Placenta previa				
No				Reference
Yes	1.952	0.452	< 0.001	7.042 (2.901-17.090)
Amniotic fluid contamination				
No				Reference
Yes	-0.176	0.522	0.736	0.839 (0.301-2.335)
HDP				
No				Reference
Yes	1.092	0.400	0.006	2.981 (1.360-6.533)
GDM				
No				Reference
Yes	-0.048	0.488	0.921	0.953 (0.366-2.480)
Uterine fibroids				
No				Reference
Yes	0.173	0.495	0.726	1.189 (0.451-3.138)
Fetal macrosomia				
No				Reference
Yes	1.134	0.550	0.039	3.109 (1.057-9.142)
Uterine atony				
No				Reference
Yes	1.157	0.364	0.001	3.181 (1.560-6.488)
Scarred uterus				
No				Reference
Yes	1.624	0.416	< 0.001	5.071 (2.244-11.462)
Assisted reproduction				
No				Reference
Yes	0.857	1.238	0.489	2.355 (0.208-26.642)

Note: BMI, body mass index; HDP, hypertensive disorder of pregnancy; GDM, gestational diabetes mellitus; OR, odds ratio; CI, confidence interval.

a significant threat to maternal life. Women of advanced maternal age (AMA) are at a higher risk of PPH compared to those of optimal childbearing age, with incidence of PPH varying

Table 5. Multivariate logistic analysis of PPH in AMA women

	B	*S.E*	*P*	OR (95% CI)
Age	0.264	0.072	< 0.001	1.302 (1.132-1.499)
Placenta previa				
No				Reference
Yes	1.667	0.525	0.002	5.295 (1.891-14.827)
HDP				
No				Reference
Yes	1.127	0.474	0.017	3.086 (1.220-7.808)
Uterine atony				
No				Reference
Yes	0.954	0.425	0.025	2.597 (1.128-5.976)
Scarred uterus				
No				Reference
Yes	1.722	0.501	< 0.001	5.593 (2.094-14.944)

Note: HDP, hypertensive disorder of pregnancy; OR, odds ratio; CI, confidence interval.

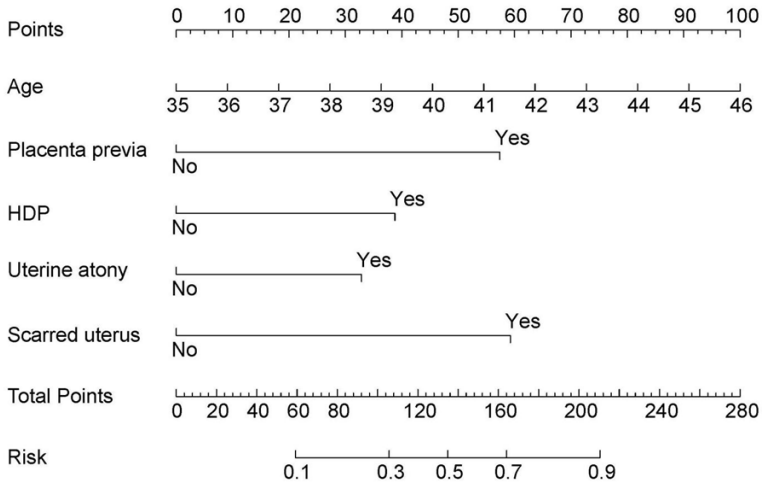

Figure 2. Nomogram prediction model for PPH in AMA women. PPH, postpartum hemorrhage; AMA, advanced maternal age; HDP, hypertensive disorder of pregnancy.

across different time periods and regions. In this study, 17.58% of the 330 AMA women undergoing natural childbirth experienced PPH, a rate consistent with previously reported range of 6.1-19.0% [3, 16]. This suggests that AMA women face a higher risk of PPH during natural childbirth. Therefore, identifying independent risk factors for PPH and developing an effective prediction model are essential for improving maternal outcomes in AMA patients. Previous studies, both domestic and international, have identified several risk factors for PPH, including age ≥ 35 years, placental abnormalities, pregnancy complications (e.g., HDP and GDM), fetal macrosomia, multiple pregnancies, scarred uterus, and polyhydramnios [17, 18]. In this study, we categorized 220 AMA into a PPH group and a non-PPH group. Multivariate logistic analysis identified age, placenta previa, HDP, uterine atony, and scarred uterus as independent risk factors for PPH in AMA women. Furthermore, the nomogram prediction model demonstrated strong predictive accuracy, making it a valuable tool for assessing PPH risk in AMA patients.

In this study, age was identified as an independent risk factor for the development of PPH. Li et al. reported that the incidence of PPH is higher in women over 35 years compared to younger women [19]. This may be attributed to the decline in physiological adaptability associated with advancing reproductive age. Research indicates that ovarian function declines with age, leading to alterations in the structure and number of uterine smooth muscle fibers, resulting in a progressive reduction in uterine contractility [20]. Therefore, AMA women undergoing natural childbirth may struggle to achieve sustained and forceful uterine contractions, resulting in incomplete vascular constriction following placental detachment. This impairment in bleeding control increases the risk of PPH. Luca et al. found that AMA women are twice as likely to experience uterine atony during natural childbirth compared to younger women, significantly increasing the risk of PPH [21]. Uterine atony is one of the leading causes of PPH, as demonstrated in the large international WOMAN's trial, where it accounted for more than 60% of cases [22]. In this study, uterine atony was also identified as an independent risk factor for PPH in AMA women. Additionally, AMA is frequently associ-

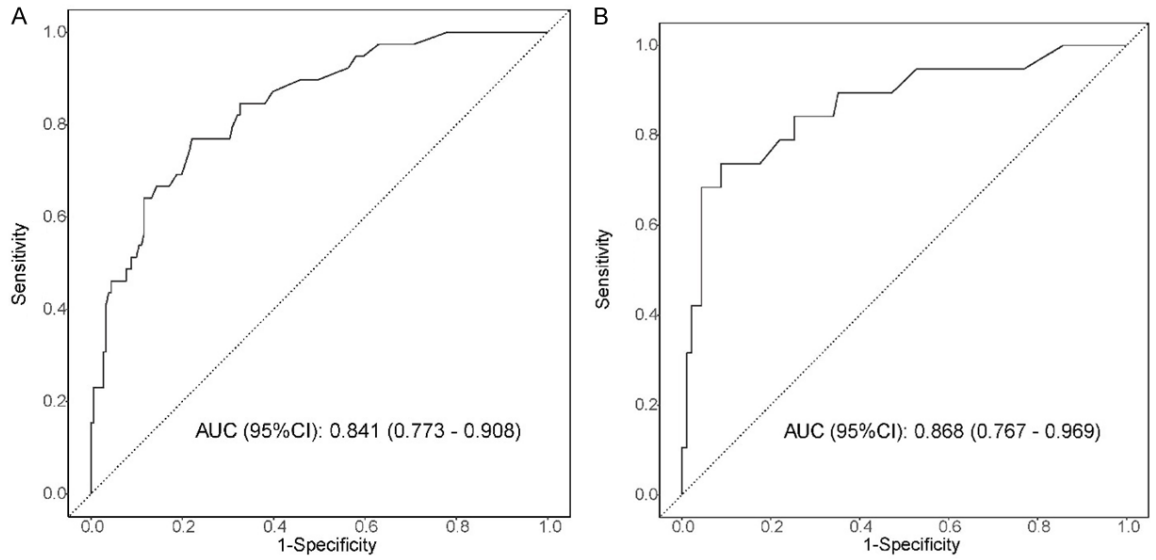

Figure 3. ROC curves of the predictive model for PPH in the training (A) and validation (B) cohorts. ROC, receiver operating characteristic; PPH, postpartum hemorrhage.

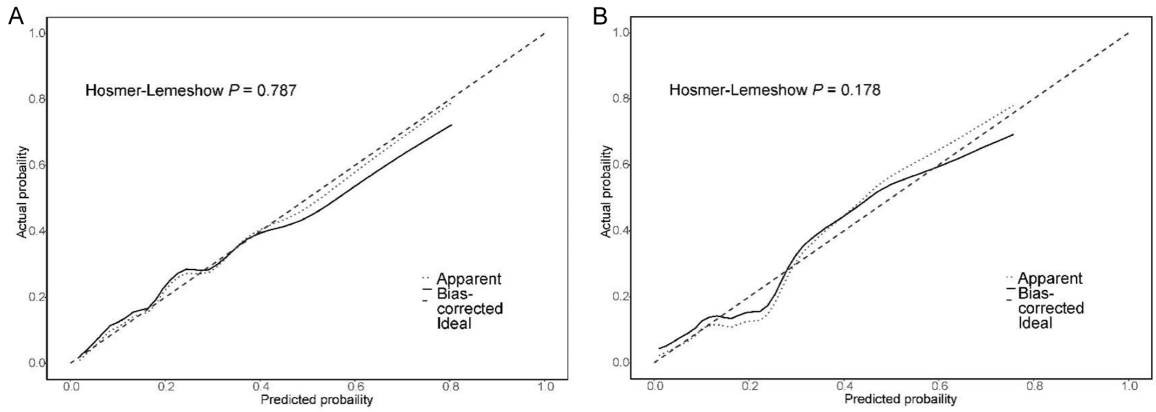

Figure 4. Calibration curves of the predictive model in the training (A) and validation (B) cohorts.

ated with an increased incidence of labor abnormalities, particularly uterine atony and insufficient cervical dilation during delivery [23]. Therefore, for AMA women presenting with uterine atony, it is crucial to enhance clinical monitoring and promptly initiate interventions, such as the administration of oxytocin and uterine massage, to reduce the risk of PPH.

This study identified placenta previa as a significant risk factor for PPH in AMA women. Placenta previa occurs when the placenta implants in the lower segment of the uterus partially or completely cover the internal cervical os. Due to the dense vascular network and abundant blood supply in this region, the risk of severe hemorrhage is heightened during delivery, as these blood vessels are more susceptible to stretching or rupture. Furthermore, placenta previa is associated with an increased risk of abnormal placental implantation, including placenta accreta or placenta increta, which can result in incomplete placental separation and uterine atony in the lower segment, thereby significantly elevating the risk of PPH. Dang et al. reported that placenta previa is a significant contributor to severe PPH and may even necessitate hysterectomy [24]. A meta-analysis further indicated that among patients with severe PPH, 32.3% had placenta previa, and 33.8% had abnormal placental implantation [25]. AMA is associated with age-related chang-

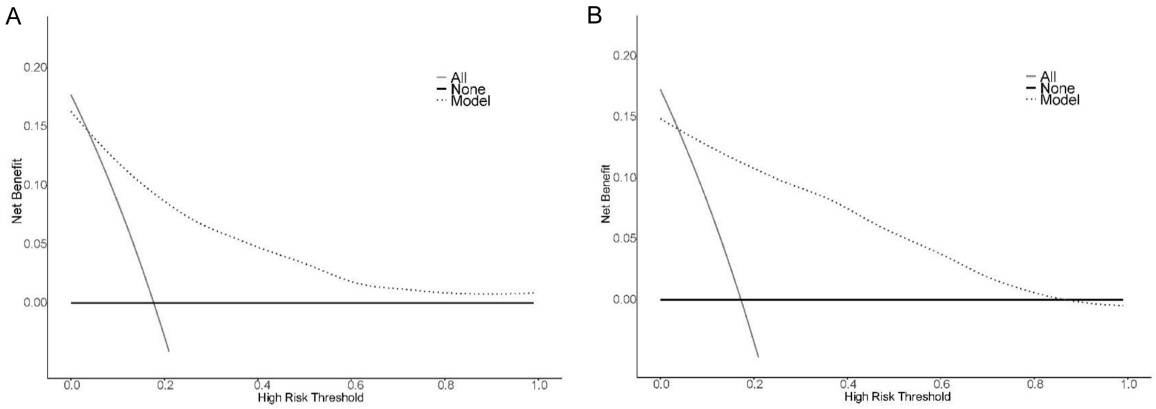

Figure 5. DCA for the predictive model in the training (A) and validation (B) cohorts. DCA, decision curve analysis.

es in the uterine muscle layer, leading to decreased contractility and impaired uterine recovery following placental detachment, further increasing the hemorrhage risk. Sahu et al. demonstrated that the incidence of placenta previa rises with advanced maternal age, a trend closely linked to endometrial aging and structural changes in the uterus [26]. Ultrasound is the primary diagnostic tool for placenta previa. By assessing the uterine artery pulsatility index (UtAPI) and resistance index (UtA-RI), it is possible to predict the depth of placental invasion and the risk of severe hemorrhage [27]. Clinically, the bleeding risk associated with placenta previa in AMA women should be evaluated using standardized protocols to optimize pregnancy outcomes.

This study identified a strong association between HDP and the risk of PPH in AMA women. HDP disrupts coagulation mechanisms during pregnancy, leading to alterations in coagulation factors and platelet dysfunction, which in turn weakens the vascular ability to regulate contraction and dilation. Following placental separation, the inability of blood vessels to constrict promptly increases the risk of prolonged hemorrhage [28]. Cagino et al. found that HDP increases vascular fragility, leading to microvascular rupture and increased vascular permeability, which exacerbates bleeding [29]. Furthermore, research has shown that the incidence of HDP is higher in older pregnant women compared to their younger counterparts, likely due to age-related declines in vascular elasticity, impairing vascular adaptation to hypertension [30]. As a result, the management of labor in AMA women with HDP should focus on the PPH risk reduction. Strategies such as blood pressure control and the use of hemostatic agents should be employed to minimize hemorrhage risk and ensure the safety of both mother and infant.

This study also identified a strong association between a scarred uterus and an increased risk of PPH in AMA women. A scarred uterus typically results from previous cesarean sections or intrauterine surgeries. Multiple studies have demonstrated that a scarred uterus increases the risk of uterine rupture during labor, thereby elevating the likelihood of PPH [31, 32]. This increased risk is likely due to the thinning of the uterine wall in the scarred region, as well as the dense and fragile blood vessels. Wang et al. [33] noted that a scarred uterus not only compromises the structural integrity of the uterus but may also impair the contractile function of the uterine muscle, further enhancing the risk of PPH. Given that AMA women often have a higher incidence of scarred uterus due to prior surgeries, a comprehensive risk assessment should be conducted before labor, and appropriate PPH prevention strategies should be implemented [34].

This study presents a nomogram-based predictive model for assessing the risk of PPH in AMA women. Among existing PPH risk assessment tools, the California Maternal Quality Care Collaborative (CMQCC) scoring system is widely used [35]. However, it primarily relies on medical history and placental abnormalities, lacking individualized risk stratification, which limits its accuracy in predicting PPH risk among AMA

women. Recent advancements in machine learning-based prediction models, including random forests, logistic regression, and deep learning, have demonstrated improved predictive accuracy [36]. Nevertheless, these models require extensive datasets and offer limited clinical interpretability, restricting their practical implementation in routine obstetric care. In contrast, the nomogram model developed in this study provides a visually intuitive and quantitative approach to PPH risk assessment in AMA women, enabling clinicians to formulate individualized management strategies. For low-risk cases, routine obstetric care with continuous labor monitoring is sufficient, minimizing unnecessary medical interventions. For high-risk cases, proactive preparation, including blood transfusion readiness and enhanced perinatal care, is essential to mitigate adverse maternal and neonatal outcomes.

In summary, this study systematically identified key independent risk factors for PPH in AMA women, including age, placenta previa, HDP, uterine atony, and scarred uterus. Utilizing these factors, a nomogram-based PPH risk prediction model was developed, alongside a stratified management strategy tailored to varying risk levels. This approach aims to enhance clinical decision-making and optimize intervention strategies to mitigate PPH-related complications in AMA pregnancies. However, this study has several limitations. First, the relatively small sample size and the fact that the data were primarily drawn from a single medical institution may limit the external validity of the findings. To enhance the generalizability of the results, future research should adopt a multi-center and large-sample study design. Moreover, while this study has identified several key risk factors for PPH, other potential contributors, such as maternal lifestyle, psychological health, and genetic predispositions, were not fully explored. Future studies should incorporate these additional factors to achieve a more comprehensive analysis, further confirming the model's applicability and reliability across diverse populations.

Conclusion

Age, placenta previa, HDP, uterine atony, and scarred uterus are independent contributors to PPH risk in AMA. The nomogram, incorporating these factors, demonstrates robust discrimination and high accuracy in predicting PPH among AMA women, enabling targeted interventions for high-risk individuals to enhance maternal safety.

Disclosure of conflict of interest

None.

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