

Original Research

Preoperative Hemoglobin Levels and Risk of Postpartum Hemorrhage in Cesarean Delivery for Placenta Previa: A Retrospective Cohort Study

Van Hien Nguyen^{1,*}, Trung Kien Nguyen¹, Thi Yen Nguyen¹, Van Ngoc Hung Do¹,
Thi Thuy Linh Bui¹, Ha Minh Hoang¹, Thi Mui Le¹, Tran Hong Quan Le¹,
Khounphaxay Phouvanan¹, Minh Tien Bui¹

¹Department of Obstetrics and Gynecology, Thai Binh University of Medicine and Pharmacy, 06122 Tran Lam, Hung Yen, Vietnam

*Correspondence: bsnguyenhienart@gmail.com (Van Hien Nguyen)

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Abstract

Background: Postpartum hemorrhage (PPH) remains a leading cause of maternal morbidity, particularly among women with placenta previa undergoing cesarean delivery. Preoperative hemoglobin (Hb) is a routinely available laboratory parameter that may reflect maternal hematologic reserve; however, its association with PPH risk in this population has not been well established. This study aimed to evaluate the relationship between preoperative Hb levels and PPH risk, assess the discriminative ability of preoperative Hb, and identify independent clinical risk factors for PPH in women undergoing cesarean section for placenta previa. **Methods:** This retrospective cohort study included 253 singleton pregnancies complicated by placenta previa who underwent cesarean section at Thai Binh Obstetrics and Gynecology Hospital between January 2024 and December 2025. Preoperative Hb levels were recorded prior to surgery. PPH was defined as estimated blood loss ≥ 1000 mL and/or the need for additional clinical intervention to achieve hemostasis. Receiver operating characteristic (ROC) analysis and multivariable logistic regression were performed to evaluate the association between preoperative Hb and PPH. **Results:** Among 252 cases with complete preoperative hemoglobin data, PPH occurred in 33 patients (13.1%). ROC analysis demonstrated modest discriminative ability of preoperative Hb for PPH (area under the curve [AUC] = 0.697; 95% confidence interval [CI]: 0.595–0.796), with an optimal cutoff of 118 g/L (sensitivity 69.7%, specificity 64.4%) identified using the Youden index. In multivariable analysis, higher preoperative Hb was independently associated with lower odds of PPH after adjustment for central placenta previa and history of previous cesarean delivery (adjusted odds ratio [aOR] = 0.95 per 1 g/L increase; 95% CI: 0.92–0.98; $p = 0.001$). Central placenta previa was independently associated with increased PPH risk (aOR = 2.48; 95% CI: 1.11–5.58; $p = 0.028$). After adjustment, history of cesarean delivery showed a positive association with PPH that did not reach statistical significance (aOR = 2.15; 95% CI: 0.95–4.87; $p = 0.066$). **Conclusions:** Lower preoperative Hb levels were independently associated with PPH in women undergoing cesarean delivery for placenta previa. Central placenta previa was likewise independently associated with increased PPH risk. Although preoperative Hb demonstrated only modest discriminative ability, it may serve as a useful adjunctive parameter for perioperative risk stratification when interpreted alongside established obstetric risk factors.

Keywords: postpartum hemorrhage; hemoglobin; placenta previa; cesarean delivery; maternal anemia

1. Introduction

Postpartum hemorrhage (PPH) remains one of the leading causes of maternal morbidity and mortality worldwide, disproportionately contributing to preventable maternal deaths, particularly in low- and middle-income countries [1]. Despite significant progress in obstetric care, perioperative monitoring, and hemorrhage management strategies, severe intraoperative hemorrhage during cesarean delivery remains a major clinical challenge, especially among women with placenta previa or a history of prior uterine surgery.

The global rise in cesarean delivery rates has been accompanied by a parallel increase in the incidence of placenta previa and placenta accreta spectrum (PAS) disorders [2,3,4,5]. Placenta previa is a well-established risk fac-

tor for severe obstetric bleeding, as implantation within the lower uterine segment limits effective myometrial contraction following placental separation [3,6]. Prior cesarean delivery further increases hemorrhagic risk through uterine scar formation and abnormal placental adherence [2,3]. Contemporary studies and international guidelines consistently identify central placenta previa and previous cesarean delivery as major determinants of hemorrhagic morbidity in this setting [6,7,8].

Recent studies have highlighted the importance of rigorous perioperative risk assessment in women at high risk of obstetric hemorrhage. Imaging findings, placental characteristics, and clinical risk factors have been investigated to support surgical planning and transfusion preparedness [8,9,10,11]. However, many of these approaches require



specialized expertise, advanced imaging interpretation, or complex assessment tools that are not universally accessible. Consequently, simple and routinely available preoperative parameters retain considerable clinical relevance, particularly in resource-limited settings.

Maternal anemia has been associated with adverse obstetric outcomes and reduced physiologic tolerance to acute intraoperative blood loss. Lower preoperative hemoglobin (Hb) levels may reflect diminished maternal hematologic reserve, potentially increasing vulnerability to hemorrhagic complications at the time of delivery. International patient blood management guidelines recommend antenatal assessment and treatment of maternal anemia to optimize maternal outcomes [12,13]. Nevertheless, the relationship between preoperative Hb and PPH in women undergoing cesarean delivery for placenta previa remains poorly characterized.

Prior studies have largely evaluated categorical anemia thresholds, transfusion outcomes, or severe hemorrhagic morbidity, rather than examining Hb as a continuous perioperative parameter [9,14]. Emerging evidence suggests that even mildly reduced or low-normal Hb concentrations may carry clinical relevance in women at elevated risk of surgical bleeding [12,13]. Studies conducted in PAS populations have further reported associations between lower preoperative Hb and increased hemorrhagic morbidity [9,10]. Nevertheless, evidence specifically addressing this association in women with placenta previa remains limited.

Importantly, lower preoperative Hb should not be interpreted as a direct causal determinant of PPH. Rather, preoperative Hb may represent a clinically accessible marker of maternal hematologic reserve and perioperative vulnerability in women at substantial bleeding risk. Clarifying this association may support more refined risk stratification and perioperative planning in high-risk obstetric populations.

Therefore, this retrospective cohort study aimed to:

(1) evaluate the association between preoperative Hb and PPH in women undergoing cesarean delivery for placenta previa;

(2) assess the discriminative ability of preoperative Hb in identifying women at increased risk of PPH;

(3) identify clinical factors independently associated with PPH through multivariable logistic regression analysis.

2. Materials and Methods

2.1 Study Design and Setting

This retrospective single-center cohort study was conducted at Thai Binh Obstetrics and Gynecology Hospital, a tertiary referral center for high-risk pregnancies in northern Vietnam. Medical records of women with placenta previa who underwent cesarean delivery between January 1, 2024 and December 1, 2025 were reviewed for eligibility.

The study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [15].

2.2 Study Population

2.2.1 Inclusion Criteria

- Singleton pregnancy;
- Placenta previa diagnosed antepartum;
- Cesarean delivery;
- Gestational age at delivery ≥ 28 weeks.

2.2.2 Exclusion Criteria

- Multifetal gestation;
- Delivery at an outside institution;
- Missing essential clinical data, including estimated blood loss, obstetric history, or placental classification;
- Known inherited coagulation disorders;
- Major maternal comorbidities, including cardiovascular disease, chronic renal disease, chronic hypertension, or pregestational diabetes mellitus;
- Major fetal anomaly or intrauterine fetal demise.

A total of 253 eligible patients were included in the present study. 1 patient with PPH had missing preoperative Hb data and was therefore excluded from all analyses involving Hb, including ROC curve analysis and logistic regression. These analyses were performed using complete-case analysis on 252 patients (33 with PPH and 219 non-PPH). No imputation was performed due to the proportion of missing data being minimal ($<1\%$).

2.3 Variables and Definitions

2.3.1 Exposure Variable

The primary exposure variable was preoperative Hb, obtained from a complete blood count performed prior to cesarean delivery and reported in g/L. Anemia was defined as Hb concentration <110 g/L, in accordance with World Health Organization criteria for anemia during pregnancy [16,17].

2.3.2 Outcome Variable

The primary outcome was PPH, defined as estimated blood loss ≥ 1000 mL during or immediately following cesarean delivery, and/or the need for additional clinical intervention in hemorrhage, including administration of additional uterotonics, blood transfusion, surgical hemostatic procedures, or intensive monitoring, consistent with international guidelines [7]. Blood loss was estimated from operative records incorporating suction volume after subtraction of amniotic fluid, visual estimation of blood absorbed in surgical drapes and gauze, and clinician-recorded blood loss documented in operative notes.

2.3.3 Clinical Variables

The following clinical variables were recorded:

- Central placenta previa: placenta completely covering the internal cervical os on ultrasound examination;
- Non-central placenta previa: placenta not completely covering the internal cervical os;
- Previous cesarean delivery: history of ≥ 1 prior cesarean sections;
- Maternal age, including the proportion of women aged ≥ 35 years;
- Parity;
- Gestational age at delivery.

2.4 Statistical Analysis

All statistical analyses were performed using SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Additional receiver operating characteristic (ROC) bootstrap analyses and exploratory model-performance assessments were performed using Python version 3.10.12 (Python Software Foundation, Wilmington, DE, USA). A two-sided p value < 0.05 was considered statistically significant.

Sensitivity analyses were performed by additionally adjusting the primary multivariable model for maternal age, nulliparity, gestational age at delivery, emergency cesarean section, and antenatal bleeding. The results of these sensitivity analyses are presented in **Supplementary Table 1**.

2.4.1 Descriptive Analysis

Continuous variables were assessed for normality using the Shapiro–Wilk test and are presented as mean $\pm$ standard deviation (SD). Categorical variables are reported as frequencies and percentages. Baseline characteristics were compared between women with and without postpartum hemorrhage (PPH). Continuous variables were compared using Student's t -test; Welch's t -test was applied when the assumption of equal variances was not met. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. A two-sided p -value < 0.05 was considered statistically significant.

2.4.2 Receiver Operating Characteristic (ROC) Curve Analysis

ROC curve analysis was performed to evaluate the discriminative ability of preoperative Hb for PPH. The area under the curve (AUC), sensitivity, specificity, and Youden index were calculated. The optimal Hb cutoff value was identified using the maximum Youden index. The 95% confidence interval (CI) for the AUC was estimated using 2000 bootstrap resamples.

2.4.3 Logistic Regression Analysis

Univariable logistic regression analysis was initially performed to evaluate unadjusted associations between candidate variables and PPH. Given the limited number of PPH events, the multivariable model was intentionally restricted to clinically relevant variables, including preoperative Hb,

central placenta previa, and previous cesarean delivery, in order to minimize model instability and the risk of overfitting [18]. This variable selection strategy was adopted to maintain an acceptable events-per-variable ratio and reduce overfitting risk.

Because anemia status was directly derived from hemoglobin values, anemia and continuous Hb were not simultaneously included in the multivariable model to avoid multicollinearity. Adjusted odds ratios (aORs) with 95% confidence intervals (CIs) were reported. Multicollinearity among variables included in the multivariable model was assessed using variance inflation factors (VIFs).

2.4.4 Sensitivity Analyses

To further assess the robustness of the primary multivariable model, exploratory sensitivity analyses were performed by individually introducing additional clinically relevant covariates that had been excluded from the primary model due to the limited number of outcome events. These variables included maternal age, parity, gestational age at delivery, emergency versus elective cesarean section, and number of antenatal bleeding episodes. The purpose of these analyses was to assess whether the association between preoperative Hb and PPH remained consistent after accounting for potential confounding, while preserving model parsimony and minimizing the risk of overfitting.

2.5 Multivariable Model Performance

The performance of the final multivariable logistic regression model was evaluated using measures of discrimination and calibration. Discrimination was assessed using AUC, whereas calibration was assessed using the Brier score. Bootstrap resampling (2000 iterations) was used to estimate 95% CIs for these performance measures. These analyses were considered exploratory and are not intended to establish or validate a clinical prediction model.

3. Results

3.1 Baseline Characteristics

Baseline maternal and obstetric characteristics are presented in Table 1. A total of 253 singleton pregnancies complicated by placenta previa and delivered by cesarean delivery were included. The mean maternal age was 33.3 ± 5.6 years, and 114 women (45.1%) were aged ≥ 35 years. Regarding parity, 61 women (24.1%) were nulliparous, 85 (33.6%) had a parity of 1, 82 (32.4%) had a parity of 2, and 25 (9.9%) had a parity of ≥ 3 . The mean gestational age at delivery was 37.3 ± 1.5 weeks. A history of previous cesarean delivery was documented in 61 patients (24.1%). The mean preoperative Hb level was 121.2 ± 13.0 g/L. Hb data were available for 252 patients, of whom 46 (18.3%) met the criteria for anemia (Hb < 110 g/L). Placenta previa was classified as non-central in 144 cases (56.9%) and central in 109 cases (43.1%). The overall incidence of PPH was 13.4% (34/253).

Table 1. Baseline characteristics of the study population (n = 253).

Variable	Value
Maternal age (years), mean $\pm$ SD	33.3 $\pm$ 5.6
Maternal age $\geq$ 35 years, n (%)	114 (45.1)
Parity, n (%)	
Nulliparous	61 (24.1)
1	85 (33.6)
2	82 (32.4)
$\geq$ 3	25 (9.9)
Gestational age at delivery (weeks), mean $\pm$ SD	37.3 $\pm$ 1.5
Previous cesarean delivery, n (%)	61 (24.1)
Preoperative Hb (g/L), mean $\pm$ SD	121.2 $\pm$ 13.0
Anemia (Hb <110 g/L), n/N (%)	46/252 (18.3)
Placenta previa type, n (%)	
Non-central placenta previa	144 (56.9)
Central placenta previa	109 (43.1)
PPH, n (%)	34 (13.4)

Note: Hb data were available for 252 patients. 1 patient with PPH had missing Hb data and was excluded from all Hb-related analyses. Hb, hemoglobin; PPH, postpartum hemorrhage; SD, standard deviation.

3.2 Between-Group Comparisons

Baseline characteristics stratified by PPH status are presented in Table 2. Women who developed PPH had significantly lower mean preoperative Hb compared with those without PPH (111.9 $\pm$ 15.5 vs. 122.6 $\pm$ 12.0 g/L; t' = 3.79; p < 0.001). Anemia (Hb <110 g/L) was also significantly more prevalent in the PPH group (36.4% vs. 15.5%; χ^2 = 8.35 p = 0.004).

Central placenta previa and previous cesarean delivery were both significantly more frequent among women who developed PPH. No significant between-group differences were observed in maternal age, gestational age at delivery, or nulliparity.

3.3 ROC Curve Analysis

The discriminative ability of preoperative Hb for PPH is summarized in Table 3. ROC analysis yielded an AUC of 0.697 (95% CI: 0.595–0.796). Using the Youden index, an optimal cutoff of 118 g/L, a sensitivity of 69.7%, a specificity of 64.4%, and a Youden index value of 0.341 (Fig. 1). These analyses were performed on 252 complete cases (33 PPH and 219 non-PPH); 1 patient with missing Hb data was excluded.

3.4 Logistic Regression Analysis

The results of univariable and multivariable logistic regression analyses are presented in Table 4. In univariable analysis, higher preoperative Hb was significantly associated with reduced odds of PPH (OR = 0.94; 95% CI: 0.91–

0.97; p < 0.001). Anemia (Hb <110 g/L), central placenta previa, and previous cesarean delivery were each associated with increased odds of PPH.

In multivariable analysis, preoperative Hb remained independently associated with reduced odds of PPH after adjustment for central placenta previa and previous cesarean delivery (aOR = 0.95; 95% CI: 0.92–0.98; p = 0.001). Central placenta previa remained significantly associated with increased risk of PPH (aOR = 2.48; 95% CI: 1.11–5.58; p = 0.028), whereas the association with previous cesarean delivery did not reach statistical significance after adjustment (aOR = 2.15; 95% CI: 0.95–4.87; p = 0.066).

Sensitivity analyses demonstrated that the association between lower preoperative Hb and increased risk of PPH remained statistically significant after individually adjusting for additional clinically relevant variables, including maternal age, parity, gestational age at delivery, emergency versus elective cesarean section, and antenatal bleeding episodes. The aOR for preoperative Hb remained stable, ranging from 0.942 to 0.950 across all sensitivity models, supporting the robustness of the primary findings.

3.5 Exploratory Model Performance

Exploratory performance measures of the multivariable model are summarized in Table 5. The multivariable model demonstrated an AUC of 0.742 (95% CI: 0.657–0.839) and a Brier score of 0.098 (95% CI: 0.067–0.123). These analyses were exploratory in nature and were intended to characterize model discrimination and calibration rather than to develop or validate a formal prediction model. Additional exploratory analysis suggested that lower preoperative Hb was associated with higher predicted probabilities of PPH.

4. Discussion

4.1 Principal Findings

In this retrospective cohort of women undergoing cesarean delivery for placenta previa, lower preoperative Hb was independently associated with increased PPH risk after adjustment for central placenta previa and previous cesarean delivery. Central placenta previa likewise remained independently associated with increased PPH risk. In contrast, the association between previous cesarean delivery and PPH was attenuated following adjustment and did not reach statistical significance.

ROC analysis demonstrated modest discriminative ability of preoperative Hb for PPH prediction. Nevertheless, preoperative Hb may provide clinically useful adjunctive information when interpreted alongside established obstetric risk factors in women undergoing high-risk cesarean delivery.

Women with an Hb below 110 g/L had significantly higher crude odds of PPH in univariable analysis. However, anemia status was not included in the multivariable

Table 2. Comparison of baseline characteristics between women with and without postpartum hemorrhage.

Variable	Non-PPH (n = 219)	PPH (n = 34)	Test statistic	p-value
Maternal age (years), mean $\pm$ SD	33.4 $\pm$ 5.8	33.0 $\pm$ 4.6	$t = 0.34$	0.732
Maternal age ≥ 35 years, n (%)	100 (45.7)	14 (41.2)	$\chi^2 = 0.24$	0.625
Gestational age at delivery (weeks), median (IQR)	38.0 (37.0–38.0)	37.5 (37.0–38.0)	$U = 3543$	0.635
Nulliparous, n (%)	57 (26.0)	4 (11.8)	$\chi^2 = 3.27$	0.070
Previous cesarean delivery, n (%)	46 (21.0)	15 (44.1)	$\chi^2 = 8.59$	0.003
Central placenta previa, n (%)	86 (39.3)	23 (67.6)	$\chi^2 = 9.67$	0.002
Preoperative Hb (g/L), mean $\pm$ SD	122.6 $\pm$ 12.0	111.9 $\pm$ 15.5	$t' = 3.79$	<0.001
Anemia (Hb <110 g/L, 252 complete cases), n (%)	34 (15.5)	12 (36.4)	$\chi^2 = 8.35$	0.004

Note: Continuous variables are summarized as mean $\pm$ SD or median (IQR), as appropriate to their distributions. Normally distributed continuous variables were compared using Student's t -test or Welch's t -test, as appropriate based on variance homogeneity. Non-normally distributed continuous variables were compared using the Mann–Whitney U test. Gestational age at delivery was non-normally distributed in both groups and was compared using the Mann–Whitney U test. Categorical variables were compared using Pearson's chi-square test or Fisher's exact test, as appropriate based on expected cell counts. Analyses of preoperative hemoglobin and anemia were based on 252 women with available hemoglobin data, including 219 women in the non-PPH group and 33 women in the PPH group; one woman in the PPH group had missing preoperative hemoglobin data. All tests were two-sided, and a p -value < 0.05 was considered statistically significant. PPH, postpartum hemorrhage; SD, standard deviation; IQR, interquartile range; Hb, hemoglobin.

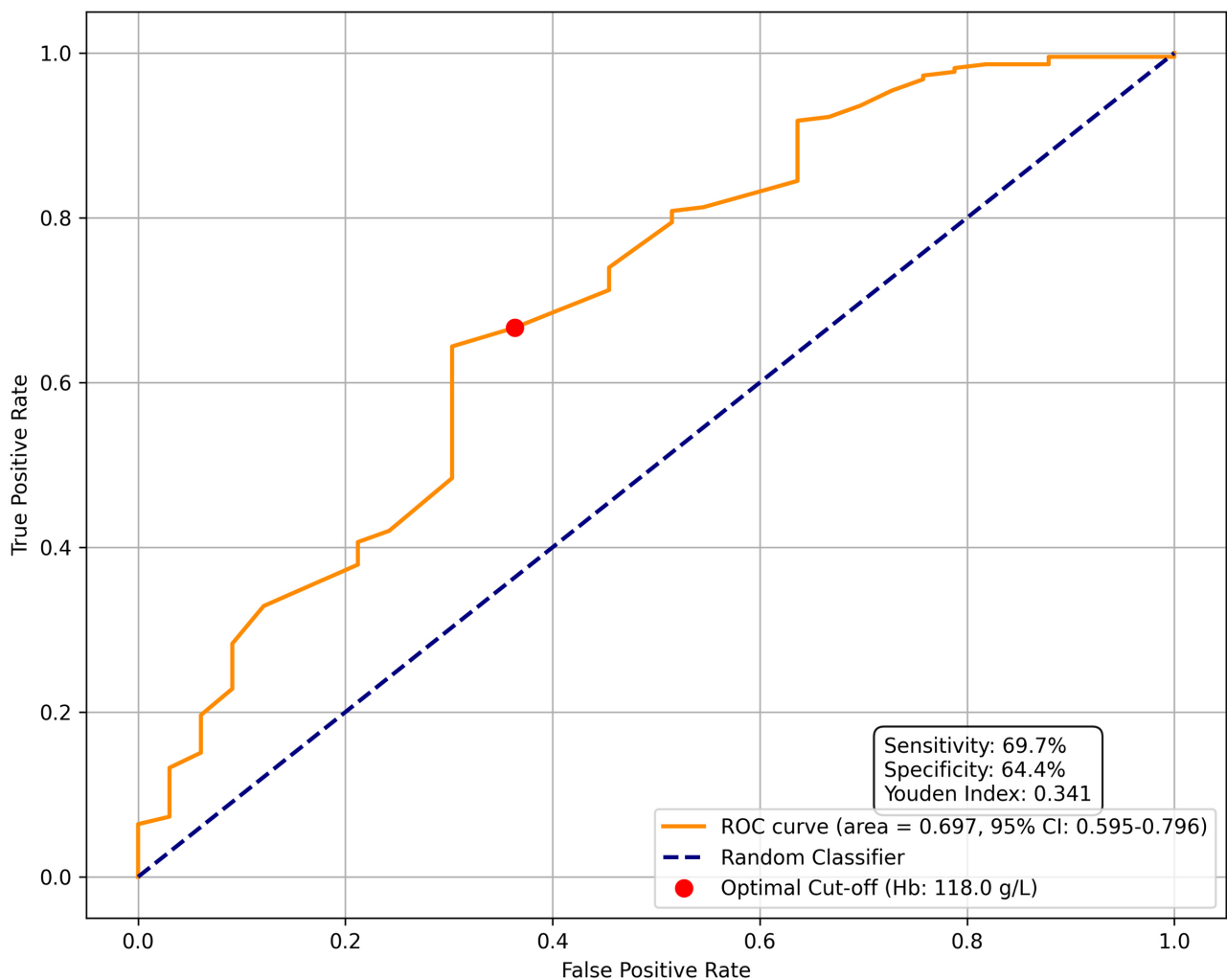
**Fig. 1. ROC curve for preoperative Hb.** AUC area under the curve; Hb, hemoglobin; ROC, receiver operating characteristic.

Table 3. ROC analysis of preoperative Hb for postpartum hemorrhage.

Parameter	Value
AUC	0.697 (95% CI: 0.595–0.796)
<i>p</i> -value	<0.001
Optimal Hb cutoff value (g/L)	118
Sensitivity (%)	69.7
Specificity (%)	64.4
Youden index	0.341

Note: Analysis was performed on 252 complete cases (33 PPH and 219 non-PPH cases). 1 patient with missing Hb data was excluded. The optimal cutoff was determined using the Youden index. The 95% CI for the AUC was estimated using 2000 bootstrap iterations. AUC, area under the curve; CI, confidence interval; Hb, hemoglobin; PPH, postpartum hemorrhage; ROC, receiver operating characteristic.

model, as it is directly derived from the continuous Hb variable and therefore collinear with the primary exposure. Furthermore, exploratory assessment of the multivariable model demonstrated acceptable overall discrimination (AUC 0.742). However, these findings should be interpreted with caution, as the model was not developed or validated as a formal clinical prediction tool.

4.2 Comparison With Existing Literature

The overall PPH incidence of 13.4% observed in this study reflects the high-risk profile of the study population, which included substantial proportions of women with central placenta previa and previous cesarean delivery. Prior studies have consistently identified central placenta previa and prior cesarean delivery as common clinical characteristics among women with placenta previa [19], and both factors have been associated with increased risk of severe obstetric hemorrhage and adverse maternal outcomes [2,3,9].

These findings are consistent with the literature emphasizing perioperative risk assessment in complex cesarean delivery. Prior studies have demonstrated that placenta previa complicated by antepartum hemorrhage is associated with a higher frequency of emergency cesarean delivery and increased adverse perinatal outcomes [8,20]. Notably, Qing et al. [20] reported that complete placenta previa was an independent risk factor for antepartum hemorrhage and that patients more frequently required emergency cesarean delivery. Similarly, Nieto-Calvache et al. [8] reported that placenta previa and previous cesarean delivery substantially increase the risk of intraoperative hemorrhage and surgical complications, particularly in women with abnormal placentation. In the present study, central placenta previa remained independently associated with PPH following multivariable adjustment, whereas the association with previous cesarean delivery was attenuated after adjustment and no longer reached statistical significance.

Studies in placenta previa and PAS populations have similarly reported associations between lower preoperative Hb and adverse hemorrhagic outcomes. Cao et al. [9] found that reduced preoperative Hb was independently associated with massive transfusion during cesarean delivery in women with anterior placenta previa and suspected PAS. Zhang et al. [10] demonstrated that increasing PAS severity was associated with markedly greater intraoperative blood loss.

Unlike many prior studies that applied categorical anemia thresholds, the present study evaluated Hb as a continuous variable in multivariable regression while additionally exploring an ROC-derived threshold. The Hb cutoff identified in this study (118 g/L) exceeded conventional third-trimester anemia thresholds. Although this value should not be interpreted as a definitive clinical threshold, it suggests that relatively low-normal Hb concentrations may still reflect reduced physiologic reserve in women at substantial risk of surgical bleeding. These findings are broadly consistent with contemporary patient blood management principles, which emphasize optimization of maternal hematologic status before delivery rather than exclusive focus on correction of severe anemia [12,13].

4.3 Pathophysiological Interpretation

Several mechanisms may explain why preoperative Hb reflects increased vulnerability to PPH rather than acting as a direct causal determinant. First, reduced Hb concentrations may reflect diminished maternal hematologic reserve, which limits oxygen-carrying capacity and reduces tolerance to acute blood loss, potentially precipitating earlier hemodynamic compromise during hemorrhagic events. Second, lower Hb may be associated with impaired physiologic adaptation to major bleeding through alterations in blood viscosity, platelet interactions, and microcirculatory dynamics, potentially compromising hemostatic efficiency. These mechanisms remain hypothetical and were not directly assessed in the present study. This consideration is particularly relevant in placenta previa, where hemorrhage arising from the lower uterine segment is often difficult to control due to limited myometrial contractility. Overall, preoperative Hb may reflect broader maternal hematologic resilience in the context of major obstetric bleeding, rather than serving solely as a marker of categorical anemia status. Accordingly, preoperative Hb is best interpreted as a surrogate marker of maternal physiologic reserve rather than a direct causal determinant of PPH.

4.4 Clinical Implications

Preoperative Hb is a simple, inexpensive, and routinely available laboratory parameter that may assist perioperative risk assessment in women with placenta previa undergoing cesarean delivery. The observed association between lower preoperative Hb and PPH suggests that maternal hematologic status may remain clinically relevant even

Table 4. Univariable and multivariable logistic regression analyses of factors associated with PPH.

Variable	Crude OR (95% CI)	β (crude)	SE (crude)	Wald χ^2 (crude)	<i>p</i> -value (crude)	Adjusted OR (95% CI)	β (adjusted)	SE (adjusted)	Wald χ^2 (adjusted)	<i>p</i> -value (adjusted)
Maternal age (per year increase)	0.98 (0.92–1.05)	−0.015	0.033	0.206	0.650	–				–
Gestational age at delivery (per week increase)	0.96 (0.76–1.23)	−0.037	0.124	0.087	0.768	–				–
Nulliparous	0.39 (0.13–1.16)	−0.936	0.555	2.845	0.092	–				–
Anemia (Hb <110 g/L)	3.11 (1.40–6.91)	1.134	0.407	7.763	0.005	–				–
Preoperative Hb (per 1 g/L increase)	0.94 (0.91–0.97)	−0.062	0.015	17.054	<0.001	0.95 (0.92–0.98)	−0.051	0.016	10.262	0.001
Central placenta previa	3.09 (1.43–6.70)	1.129	0.394	8.199	0.004	2.48 (1.11–5.58)	0.910	0.413	4.857	0.028
Previous cesarean delivery (≥ 1)	2.77 (1.29–5.94)	1.019	0.389	6.854	0.009	2.15 (0.95–4.87)	0.767	0.417	3.391	0.066

Note: Analyses were performed on 252 complete cases (33 PPH events). 1 patient with missing Hb data was excluded. Variables included in the multivariable model were selected based on clinical relevance and the limited number of outcome events to minimize overfitting. Because anemia status was directly derived from continuous Hb values, anemia and continuous Hb were not simultaneously included in the multivariable model to avoid multicollinearity. All VIFs were 1.0, indicating no evidence of multicollinearity. CI, confidence interval; Hb, hemoglobin; PPH, postpartum hemorrhage; OR, odds ratio; VIF, variance inflation factor.

Table 5. Exploratory performance measures of the multivariable logistic regression model.

Parameter	Value	<i>p</i> -value
AUC	0.742 (95% CI: 0.657–0.839)	<0.001
Brier score	0.098 (95% CI: 0.067–0.123)	

Note: Analyses were performed on 252 complete cases (33 PPH events). These measures were exploratory and intended to describe overall model discrimination and calibration rather than to establish or validate a clinical prediction model. AUC, area under the curve; CI, confidence interval; Brier, Brier score.

in women who do not meet conventional anemia criteria. Although the ROC-derived threshold of 118 g/L exceeded the study definition of anemia (<110 g/L), this threshold should be interpreted with caution given the modest discriminative performance of preoperative Hb alone. These findings also support the potential value of antenatal optimization of maternal hematologic status in women at increased risk of obstetric hemorrhage. However, causal inferences cannot be established given the retrospective observational design, and these findings should not be interpreted as evidence that correction of Hb alone is sufficient to prevent PPH. Preoperative Hb should therefore be regarded as an adjunctive factor within comprehensive obstetric risk assessment framework, rather than as a standalone predictor of hemorrhagic risk.

4.5 Strengths and Limitations

This study examined a clinically important and potentially modifiable risk factor for PPH in a high-risk obstetric population. Preoperative Hb measurement is widely available in routine clinical practice, which supports the practical applicability of these findings. The study further assessed Hb both as a continuous variable and in relation to an ROC-derived threshold.

Several limitations should be acknowledged.

First, the retrospective single-center design may limit generalizability and introduce selection bias. Second, blood loss estimation during cesarean delivery is inherently imprecise. Third, the relatively small number of PPH events limited multivariable model complexity and reduced statistical precision. Although additional potential confounders were considered, inclusion of a larger number of variables in the primary multivariable model was limited by the small number of outcome events. Therefore, a parsimonious primary model was selected to minimize the risk of overfitting. Nevertheless, exploratory sensitivity analyses incorporating selected additional clinical variables yielded similar estimates for the association between preoperative Hb and PPH, supporting the stability and robustness of the main findings. Residual confounding cannot be completely excluded despite multivariable adjustment and sensitivity analyses. Finally, analyses of discrimination, ROC-derived thresholds, and overall model performance were

exploratory in nature and should be interpreted as descriptive findings rather than as evidence supporting formal clinical risk prediction.

4.6 Future Directions

Prospective multicenter studies are needed to confirm these findings in larger and more diverse populations and to evaluate whether antenatal optimization of maternal Hb may reduce hemorrhagic morbidity in women with placenta previa and other high-risk obstetric conditions. Further research integrating hematologic parameters with established obstetric risk factors and placental characteristics may contribute to the development of improved perioperative risk assessment strategies in women at elevated risk of severe obstetric bleeding.

5. Conclusions

In this retrospective cohort of women undergoing cesarean delivery for placenta previa, lower preoperative Hb and central placenta previa were each independently associated with increased PPH risk. Although preoperative Hb alone demonstrated modest discriminative ability for PPH, it may serve as a clinically useful adjunctive parameter when interpreted alongside established obstetric risk factors. These findings further suggest that relatively low Hb concentrations, even those above conventional anemia thresholds, may carry clinical relevance in women at high risk of obstetric hemorrhage. Given the retrospective observational design and limited number of PPH events, these findings should be interpreted with caution. Prospective multicenter studies are warranted to confirm these associations and to clarify the potential role of antenatal optimization of maternal hematologic status in reducing hemorrhagic morbidity in this high-risk population.

Abbreviations

aOR, adjusted odds ratio; AUC, area under the curve; CI, confidence interval; Hb, hemoglobin; OR, odds ratio; PAS, placenta accreta spectrum; PPH, postpartum hemorrhage; ROC, receiver operating characteristic; SD, standard deviation; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology; VIF, variance inflation factor.

Availability of Data and Materials

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

Author Contributions

VHN conceived and designed the study, performed data analysis, interpreted the results, and drafted the manuscript. TKN, TYN, VNHD, TTLB, HMM, and TML contributed to data collection, data verification, and clinical

cal interpretation. THQL and KP contributed to statistical review and critical revision of the manuscript. MTB supervised the study, contributed to study design and interpretation of findings, and critically revised the manuscript for important intellectual content. All authors contributed to editorial revisions, read and approved the final manuscript, and have made sufficient contributions to the work to be accountable for all aspects in accordance with ICMJE authorship criteria.

Ethics Approval and Consent to Participate

The study was approved by the Institutional Review Board of Thai Binh Obstetrics and Gynecology Hospital (Approval No. 11/GCN-HĐĐĐ-YDTB). Given the retrospective design and use of anonymized clinical data, the requirement for informed consent was waived. All procedures were conducted in accordance with the principles of the Declaration of Helsinki.

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Conflicts of Interest

The authors declare no conflicts of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at <https://doi.org/10.31083/CEOG52949>.

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