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Original Research

Influencing Factors and Predictive Value of Postpartum Hemorrhage Following Cesarean Myomectomy: A Retrospective Cohort Study

Xinhui Wang[1,2], Dan Zhang[3,4,*], Qing Sun[1], Xiling Yi[4], Hengyu Cai[5]

[1]Postgraduate Training Base of Shenyang Women's and Children's Hospital of Jinzhou Medical University, 110011 Shenyang, Liaoning, China
[2]Department of Obstetrics and Gynecology, Shenyang 245 Hospital, 110041 Shenyang, Liaoning, China
[3]Shenyang Clinical Medical Research Center for Obstetrics and Gynecology, Shenyang Women's and Children's Hospital, 110011 Shenyang, Liaoning, China
[4]Department of Obstetrics, Shenyang Women's and Children's Hospital, 110011 Shenyang, Liaoning, China
[5]Department of Anesthesiology, Shenyang Women's and Children's Hospital, 110011 Shenyang, Liaoning, China
*Correspondence: dan.zhang.ln@163.com (Dan Zhang)
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Abstract

Background: Postpartum hemorrhage (PPH) is a major cause of maternal mortality, and uterine fibroids are a common condition that may contribute to this risk. This study aimed to determine the risk factors for PPH following cesarean myomectomy and to evaluate their predictive value. **Methods**: We conducted a retrospective analysis of 1002 women with fibroids ≥4 cm in diameter who underwent cesarean myomectomy at the Shenyang Women's and Children's Hospital from January 2014 to November 2022. The PPH and non-PPH groups consisted of 109 and 893 patients, respectively. Patient, clinical, and surgical data were collected from medical records. Factors associated with PPH were identified through univariate and multivariable logistic regression analyses. A receiver operating characteristic (ROC) curve analysis was used to assess the predictive value of independent risk factors for PPH. Propensity score matching analysis was used to determine whether bilateral uterine artery ligation before myomectomy and the use of potent uterotonic drugs during this procedure protected against PPH. **Results**: Independent risk factors for PPH included multiple fibroids, specific sites of fibroids (located in the lower segment of the uterus, cervix, uterine cornu, or adjacent to the uterine vessels or the interstitial part of the fallopian tube), a longer surgery duration, and a larger fibroid size (diameter >7.5 cm for single fibroids and total diameter >14.5 cm for multiple fibroids). The results of the propensity score matching analysis indicated that bilateral uterine artery ligation and the administration of potent uterotonic drugs before myomectomy were protective factors against PPH. ROC curve analysis showed that both the maximum diameter of a single uterine fibroid and the sum of the maximum diameters of multiple uterine fibroids are predictive of PPH risk. **Conclusions**: Cesarean myomectomy is relatively safe for fibroids located at non-specific sites with a diameter ≤7.5 cm (single) or a total diameter ≤14.5 cm (multiple). The duration of surgery should be minimized. In high-risk cases, bilateral uterine artery ligation and the administration of potent uterotonic drugs before myomectomy should be considered.

Keywords: cesarean section; uterine fibroids; postpartum hemorrhage; uterine artery ligation

1. Introduction

Postpartum hemorrhage (PPH), which is defined as blood loss ≥1000 mL in the first 24 hours after delivery or cesarean section, remains a leading cause of maternal mortality worldwide. The rapid onset and potential severity of PPH necessitate urgent identification of modifiable risk factors [1]. Uterine fibroids are non-cancerous tumors caused by excessive growth of uterine smooth muscle cells and a common gynecological condition affecting women of reproductive age [2]. Accumulating evidence has demonstrated a strong association between uterine fibroids and adverse pregnancy outcomes. These outcomes include maternal complications, such as PPH and others that involve the fetus, such as preterm birth and even extreme prematurity (<28 gestational weeks). Notably, the global prevalence of uterine fibroids has been increasing [3–5]. Routine performance of myomectomy during cesarean section is controversial. However, in specific cases, myomectomy is safe and feasible and is associated with favorable outcomes [6]. The advantages of addressing uterine fibroids at the time of cesarean section include reducing fibroid-related postpartum complications and obviating the requirement for later uterine fibroid resection. Liu *et al*. [7] showed that after cesarean section, 48 patients (aged 26–41 years) had a dominant leiomyoma >50 mm. During the follow-up period, for an average of 38.5 months, 11 patients underwent surgery for symptomatic fibroids. Therefore, simultaneous removal of uterine fibroids during cesarean section, also known as cesarean myomectomy, has been advocated [8–11].

Nonetheless, PPH remains a serious complication because cesarean myomectomy may increase the risk of PPH [12,13]. A recent Cochrane review of cesarean myomectomy concluded that the available evidence for all critical outcomes is of very low certainty [14]. Therefore, drawing definitive conclusions regarding the effects of cesarean myomectomy on the risk of requiring blood transfusion, risk of hemorrhage, length of hospitalization, duration of surgery, and risk of major surgery at the time of the procedure is not possible.

This study aimed to identify the risk factors for PPH following cesarean myomectomy and to evaluate their predictive value. Hopefully, our findings will assist in reducing the incidence of PPH and developing targeted interventions for high-risk pregnancies.

2. Materials and Methods

2.1 Study Design and Setting

This retrospective cohort study included women who underwent cesarean myomectomy at Shenyang Women's and Children's Hospital from January 2014 to November 2022. The inclusion criteria were as follows: (1) elective cesarean delivery with concurrent myomectomy; (2) uterine fibroids $\geq$4 cm in diameter [15]; (3) gestational age $\geq$28 weeks; and (4) standardized combined spinal-epidural anesthesia and oxytocin protocol (10 IU intravenous + 10 IU intramyometrial oxytocin). Women who underwent emergency cesarean section, induced labor, or uterine surgery in addition to cesarean myomectomy were excluded. We also excluded women with any of the following conditions: prior uterine contractions, uterine malformations, placental abnormalities, multiple pregnancies, cardiovascular disease, cerebrovascular disease, hepatic dysfunction, renal dysfunction, an endocrine disorder, a coagulation disorder, and moderate-to-severe anemia. Patients with incomplete data were also excluded.

The following data were collected from medical records: maternal age, height, weight, gestational age at delivery, parity, newborn weight, duration of surgery, number and location of fibroids, maximum diameter of individual uterine fibroids, sum of the maximum diameters (in those with multiple fibroids), presence of fibroid degeneration, bilateral uterine artery ligation before myomectomy, and use of potent uterotonic drugs during surgery.

2.2 Definitions

(1) PPH [1] was defined as blood loss $\geq$1000 mL in the first 24 hours following cesarean section and estimated using a combination of the volume method, area method, weight method, and hemoglobin level determination. The volume of surgical blood loss was estimated by subtracting the volume of amniotic fluid aspirated from the total volume of blood and fluid aspirated during the procedure. The area of soaked dressings (with blood-soaked gauze pad area) was calculated as follows: 10 $\times$ 10 cm = 10 mL, where 1 cm^2 corresponds to 1 mL of blood loss. In the weight method, blood loss (mL) was calculated as follows: [wet weight of the blood-soaked dressing after fetal delivery (g) – dry weight of the dressing before blood collection (g)]/1.05. The estimated blood loss was approximately 400 mL for every 10 g/L decrease in hemoglobin.

(2) Specific sites of uterine fibroids [16] were defined as those located in the lower segment of the uterus, cervix, or uterine cornu, or adjacent to the uterine vessels or the interstitial part of the fallopian tube. The prevalence of uterine fibroids was lower in these sites than in the fundus and body of the uterus. We mainly focused on the more common locations because of their higher prevalence and greater clinical significance.

(3) Potent uterotonic agents [17] included carboprost tromethamine or carbetocin. Some patients required these agents in addition to the standard dose of oxytocin.

(4) The duration of surgery was defined as the time elapsed from the start of the procedure to the end of the procedure.

2.3 Statistical Analysis

Statistical analyses were performed using SPSS software version 27.0 (IBM Corp., Armonk, NY, USA) and R software version 4.4.2 (R Foundation for Statistical Computing, Vienna, Austria, https://www.R-project.org), and $p < 0.05$ was considered significant. Categorical variables are presented as the number with percentage and were compared using the chi-square test. Normality of continuous variables was tested using the Shapiro-Wilk test. Non-normally distributed continuous variables are presented as the median with interquartile range and were compared using the Mann-Whitney U test. Logistic regression models were used to analyze the risk factors for PPH by calculating odds ratios (ORs) with 95% confidence intervals (CIs). In the multivariate analysis, variables were selected based on theoretical and clinical relevance, rather than relying solely on univariate statistical significance. We performed propensity score matching (PSM) to minimize selection bias when comparing intraoperative intervention methods. Covariates for matching were selected according to variables with statistical significance ($p < 0.05$) identified in the univariate analysis (Table 1), ensuring balanced baseline characteristics between the groups. We applied a 1:3 matching ratio using nearest-neighbor matching with a caliper width of 0.03, matching each case to three controls. To assess the balance between the treated and control groups after PSM, we evaluated the distribution of propensity scores before and after matching. Specifically, we generated histograms to visually compare the propensity score distributions in both groups, with separate plots for the prematching and post-matching stages. This approach ensured sufficient overlap in the propensity score distributions of the matched pairs. Conditional logistic regression was used to analyze the factors influencing matched groups. Receiver operating characteristic curves were plotted to assess the predictive value of independent risk factors.

Table 1. Patients' characteristics according to the groups.

Characteristic	Non-PPH group (n = 893)	PPH group (n = 109)	U/χ^2	*p*-value
Age (years)	32 (29, 36)	33 (30, 37)	44,391.500	0.133
BMI (kg/m^2)			0.237	0.888
Normal weight (18.50–23.99)	44 (4.93)	5 (4.59)		
Overweight (24.00–27.99)	272 (30.46)	31 (28.44)		
Obesity (≥28.00)	577 (64.61)	73 (66.97)		
Gestational weeks at delivery	39 (38.40, 39.40)	39 (38.60, 39.60)	48,048	0.828
Parity			0.119	0.730
Primipara	759 (84.99)	94 (86.24)		
Multipara	134 (15.01)	15 (13.76)		
Newborn weight (g)	3370 (3100, 3690)	3430 (3195, 3770)	44,076.500	0.107
Operative duration (min)	52 (41, 64)	65 (50, 88)	31,289.500	<0.001
Number of fibroids			16.229	<0.001
Multiple fibroids	337 (37.74)	63 (57.80)		
Solitary fibroid	556 (62.26)	46 (42.20)		
Location of uterine fibroids			109.423	<0.001
Uterine fibroids in special locations	62 (6.94)	43 (39.45)		
Uterine fibroids in non-special locations	831 (93.06)	66 (60.55)		
Fibroid degeneration			2.052	0.152
No	802 (89.81)	93 (85.32)		
Yes	91 (10.19)	16 (14.68)		
Diameter of a single uterine fibroid (cm)	5 (4, 6)	8 (6, 9)	5932	<0.001
Sum of the maximum diameters of multiple uterine fibroids (cm)	9 (7, 12)	15 (9, 20)	5657	<0.001
Administration of potent uterine contraction-inducing medication prior to myomectomy			2.691	0.101
No	789 (88.35)	102 (93.58)		
Yes	104 (11.65)	7 (6.42)		
Bilateral uterine artery ligation prior to myomectomy			0.082	0.775
No	829 (92.83)	102 (93.58)		
Yes	64 (7.17)	7 (6.42)		

PPH, postpartum hemorrhage; BMI, body mass index.

Table 2. Multivariable logistic regression analysis.

Characteristics	β	SE	Z	*p*-value	OR	95% CI
Operative duration	0.025	0.005	4.833	<0.001	1.025	1.015–1.035
Number of fibroids (multiple/single)	0.654	0.238	2.750	0.006	1.923	1.209–3.078
Location of uterine fibroids (special/non-special)	2.092	0.255	8.202	<0.001	8.099	4.911–13.376
Age	–0.020	0.027	–0.727	0.467	0.981	0.930–1.033

SE, standard error; OR, odds ratio; 95% CI, 95% confidence interval.

3. Results

3.1 Univariate Analysis of PPH Following Cesarean Section Myomectomy

A total of 1002 patients met the study criteria and were included in the analysis. Among these, 109 experienced PPH (PPH group) and 893 did not (non-PPH group). The patients' characteristics according to the groups are shown in Table 1. The duration of surgery, individual uterine fibroid diameter, sum of the maximum diameters of multiple uterine fibroids, number of uterine fibroids, and fibroid location were significantly different between the groups.

3.2 Logistic Regression Analysis of Factors Associated With PPH

Although age was not statistically significant in the univariate analysis (p = 0.133), it was included in the multivariate analysis due to its clinical importance. A longer duration of surgery (OR, 1.025; 95% CI, 1.015–1.035; $p < 0.001$), multiple uterine fibroids (OR, 1.923; 95% CI, 1.209–3.078; $p < 0.01$), and specific sites of uterine fibroids (OR, 8.099; 95% CI, 4.911–13.376; $p < 0.001$) were independent risk factors for PPH in the multivariable logistic regression analysis (Table 2).

Table 3. Univariate analysis of subgroup with single uterine fibroid.

Characteristic	Non-PPH group (n = 556)	PPH group (n = 46)	U/χ^2	*p*-value
Age (years)	32 (29, 35)	32.5 (29, 37)	11,644.500	0.312
BMI (kg/m^2)			1.552	0.460
Normal weight (18.50–23.99)	35 (6.29)	1 (2.17)		
Overweight (24.00–27.99)	166 (29.86)	16 (34.78)		
Obesity ($\geq$28.00)	355 (63.85)	29 (63.05)		
Gestational weeks at delivery	39 (38.43, 39.43)	39 (38.57, 39.57)	12,083	0.534
Parity			0.851	0.356
Primipara	467 (83.99)	41 (89.13)		
Multipara	89 (16.01)	5 (10.87)		
Newborn weight (g)	3375 (3110.00, 3682.50)	3437.50 (3212.50, 3787.50)	11,458.500	0.241
Operative duration (min)	47 (39.00, 58.00)	65 (48.50, 73.75)	7670.500	<0.001
Bilateral uterine artery ligation prior to myomectomy			Fisher	0.386
No	538 (96.76)	46 (100.00)		
Yes	18 (3.24)	0 (0.00)		
Administration of potent uterine contraction-inducing medication prior to myomectomy			0.065	0.799
No	520 (93.53)	44 (95.65)		
Yes	36 (6.47)	2 (4.35)		
Fibroid degeneration			Fisher	0.039
No	504 (90.65)	37 (80.43)		
Yes	52 (9.35)	9 (19.57)		
Diameter of a single uterine fibroid (cm)	5 (4, 6)	8 (6, 9)	5932	<0.001
Location of uterine fibroids			76.824	<0.001
Uterine fibroids in non-special locations	515 (92.63)	23 (50.00)		
Uterine fibroids in special locations	41 (7.37)	23 (50.00)		

Table 4. Logistic regression analysis in patients with a single uterine fibroid.

Characteristics	β	SE	Z	*p*	OR	95% CI
Diameter of a single uterine fibroid	0.534	0.084	40.25	<0.001	1.705	1.446–2.011
Duration of surgery	0.016	0.010	2.650	0.104	1.016	0.997–1.035
Location of uterine fibroids (special/non-special)	2.806	0.413	46.25	<0.001	16.543	7.369–37.138
Age	0.003	0.043	0.004	0.947	1.003	0.922–1.090
Myoma degeneration (No/Yes)	0.586	0.500	1.373	0.241	1.797	0.674–4.791

To better analyze the subgroup differences between patients with a single uterine fibroid and those with multiple uterine fibroids, we performed subgroup analyses and conducted univariate and multivariate regression analyses for each group. The specific details can be found in Table 3 (Univariate analysis of the subgroup with a single uterine fibroid), Table 4 (Logistic regression analysis in patients with a single uterine fibroid), Table 5 (Univariate analysis of the subgroup with multiple uterine fibroids), and Table 6 (Logistic regression analysis in patients with multiple uterine fibroids). In patients with a single uterine fibroid, a greater fibroid diameter was an independent risk factor for PPH. The odds of PPH increased as the diameter increased (OR, 1.705; 95% CI, 1.446–2.011; $p < 0.001$; Table 4). Similarly, in those with multiple fibroids, an increased sum of the maximum diameters was an independent risk factor (OR, 1.177; 95% CI, 1.112–1.245; $p < 0.001$; Table 6).

3.3 Uterine Fibroid Diameter and Prediction of PPH

The sensitivity of a single uterine fibroid diameter in predicting PPH was 0.587, with a specificity of 0.872 and an area under the receiver operating characteristic curve of 0.768. The optimal cutoff value was 7.5 cm, with an accuracy of 0.850. These findings suggested that the diameter of a single uterine fibroid was a reliable predictor of PPH (Table 7 and Fig. 1).

The sensitivity of the sum of the maximum diameters of multiple uterine fibroids in predicting PPH was 0.556, with a specificity of 0.846 and an area under the receiver operating characteristic curve of 0.734. The optimal cutoff value was 14.5 cm, with an accuracy of 0.800. These findings indicated that the combined maximum diameters of multiple uterine fibroids also reliably predicted PPH (Table 8 and Fig. 2).

Table 5. Univariate analysis of subgroup with multiple uterine fibroids.

Characteristic	Non-PPH group (n = 337)	PPH group (n = 63)	U/χ^2	*p*-value
Age (years)	33 (30.00, 37.00)	34 (31.00, 36.50)	10,601	0.987
Body mass index (BMI) (kg/m^2)			3.361	0.186
Normal weight (18.50–23.99)	9 (2.67)	4 (6.35)		
Overweight (24.00–27.99)	106 (31.45)	15 (23.81)		
Obesity (≥28.00)	222 (65.88)	44 (69.84)		
Gestational weeks at delivery	39 (38.43, 39.57)	39 (38.57, 39.43)	10,817.500	0.811
Parity			0.284	0.594
Primipara	292 (86.65)	53 (84.13)		
Multipara	45 (13.35)	10 (15.87)		
Newborn weight (g)	3360 (3040.00, 3690.00)	3410 (3187.50, 3760.00)	9566.500	0.213
Operative duration (min)	58 (48.00, 70.00)	70 (50.00, 93.50)	7923	0.001
Bilateral uterine artery ligation prior to myomectomy			0.298	0.585
No	291 (86.35)	56 (88.89)		
Yes	46 (13.65)	7 (11.11)		
Administration of potent uterine contraction-inducing medication prior to myomectomy			5.331	0.021
No	269 (79.82)	58 (92.06)		
Yes	68 (20.18)	5 (7.94)		
Fibroid degeneration			0.011	0.916
No	298 (88.43)	56 (88.89)		
Yes	39 (11.57)	7 (11.11)		
Diameter of a single uterine fibroid (cm)	9 (7, 12)	15 (9, 20)	5657	<0.001
Location of uterine fibroids			37.560	<0.001
Uterine fibroids in non-special locations	316 (93.77)	43 (68.25)		
Uterine fibroids in special locations	21 (6.23)	20 (31.75)		

Table 6. Logistic regression analysis in patients with multiple uterine fibroids.

Characteristics	β	SE	Z	*p*-value	OR	95% CI
Sum of the maximum diameters of multiple uterine fibroids	0.163	0.029	32.049	<0.001	1.177	1.112–1.245
Duration of surgery	0.014	0.007	4.448	0.035	1.014	1.001–1.027
Location of uterine fibroids (special/non-special)	2.209	0.432	26.086	<0.001	9.102	3.900–21.244
Age	–0.092	0.041	4.968	0.026	0.913	0.842–0.989
Administration of potent uterine contraction-inducing medication prior to myomectomy (No/Yes)	–2.094	0.543	14.856	<0.001	0.123	0.042–0.357

Table 7. Receiver operating characteristic curve analysis of a single uterine fibroid diameter as a predictor of postpartum hemorrhage.

Characteristics	Cutoff value	Sensitivity	Specificity	AUC (95% CI)	Accuracy	*p*-value
Diameter of a single uterine fibroid (cm)	7.5	0.587	0.872	0.768 (0.689–0.847)	0.850	<0.05

AUC, area under the receiver operating characteristic curve.

Table 8. Receiver operating characteristic curve analysis of the sum of the maximum diameters of multiple uterine fibroids as a predictor of postpartum hemorrhage.

Characteristics	Cutoff value	Sensitivity	Specificity	AUC (95% CI)	Accuracy	*p*-value
Sum of the maximum diameters of multiple uterine fibroids (cm)	14.5	0.556	0.846	0.734 (0.662–0.805)	0.800	<0.05

AUC, area under the receiver operating characteristic curve.

3.4 Effect of Pre-myomectomy Interventions on PPH

Significant confounding variables were present because of selection bias arising from the performance of bilateral uterine artery ligation before myomectomy and the use of potent uterotonic drugs during cesarean myomectomy. PSM was used to effectively mitigate these and in-

Table 9. Patients' characteristics in the propensity score-matched groups.

Characteristics	Non-PPH group (n = 213)	PPH group (n = 88)	U/χ^2	*p*-value
Age (years)	32 (31, 36)	33 (30, 36)	9676	0.658
Body mass index (BMI) (kg/m^2)			Fisher	0.921
Normal weight (18.50–23.99)	9 (4.23)	4 (4.55)		
Overweight (24.00–27.99)	59 (27.70)	26 (29.55)		
Obesity (≥28.00)	145 (68.08)	58 (65.91)		
Gestational weeks at delivery	39.1 (38.60, 39.60)	39 (38.60, 39.40)	10,119	0.276
Parity			0.099	0.752
Primipara	186 (87.32)	78 (88.64)		
Multipara	27 (12.68)	10 (11.36)		
Newborn weight (g)	3200 (3110, 3800)	3410 (3180, 3800)	0.129	0.898
Operative duration (min)	60 (48.00, 75.00)	65 (47.00, 75.50)	9136	0.732
Number of fibroids			0.039	0.843
Multiple fibroids	99 (46.48)	42 (47.73)		
Solitary fibroid	114 (53.52)	46 (52.27)		
Location of uterine fibroids			4.645	0.031
Uterine fibroids in special locations	39 (18.31)	26 (29.55)		
Uterine fibroids in non-special locations	174 (81.69)	62 (70.45)		
Fibroid degeneration			0.268	0.605
No	184 (86.38)	74 (84.09)		
Yes	29 (13.62)	14 (15.91)		
Diameter of a single uterine fibroid (cm)	5 (4.00, 6.00)	8 (6.00, 9.75)	860.500	<0.001
Sum of the maximum diameters of multiple uterine fibroids (cm)	10 (8.00, 13.38)	15.5 (9.12, 20.00)	1656.500	<0.001
Administration of potent uterine contraction-inducing medication prior to myomectomy			11.897	<0.001
No	162 (76.06)	82 (93.18)		
Yes	51 (23.94)	6 (6.82)		
Bilateral uterine artery ligation prior to myomectomy			4.848	0.028
No	185 (86.85)	84 (95.45)		
Yes	28 (13.15)	4 (4.55)		

Table 10. Conditional logistic regression analysis of the effect of pre-myomectomy interventions on postpartum hemorrhage after propensity score matching.

Characteristics	β	SE	Z	*p*-value	OR	95% CI
Pre-myomectomy bilateral uterine artery ligation (Yes/No)	–1.745	0.622	–2.805	<0.01	0.175	0.052–0.591
Pre-myomectomy use of potent uterotonic drugs (Yes/No)	–1.744	0.471	–3.703	<0.001	0.175	0.069–0.440

vestigate the potential effect of pre-myomectomy interventions on PPH. A 1:3 matching ratio was used to match patients in the PPH group with those in the non-PPH group using a caliper value of 0.03 to ensure the precision and reliability of the matching process. However, due to some extreme propensity scores in the PPH group, it was not possible to find three sufficiently close matched samples in the non-PPH group. As a result, the actual matching ratio was lower than 1:3, as shown in Table 9.

Prior to matching, significant differences in the surgery duration, number of fibroids, and fibroid location were observed between the two groups. Propensity scores were derived using a logistic regression model that included the following variables: surgery duration, number of fibroids, and fibroid location. These variables were chosen because they may have a significant effect on the risk of PPH. After matching, the proportions of patients who had undergone bilateral uterine artery ligation prior to myomectomy and had received potent uterotonic drugs were significantly different (Table 9). These results suggested a notable protective effect of pre-myomectomy interventions on PPH.

To assess the quality of PSM, the distribution of propensity scores was compared between the PPH and non-PPH groups before and after matching using a distribution histogram. As shown in Fig. 3, there were notable differences in the distributions between the groups before matching. However, the distributions were nearly identical after matching, which indicated successful matching.

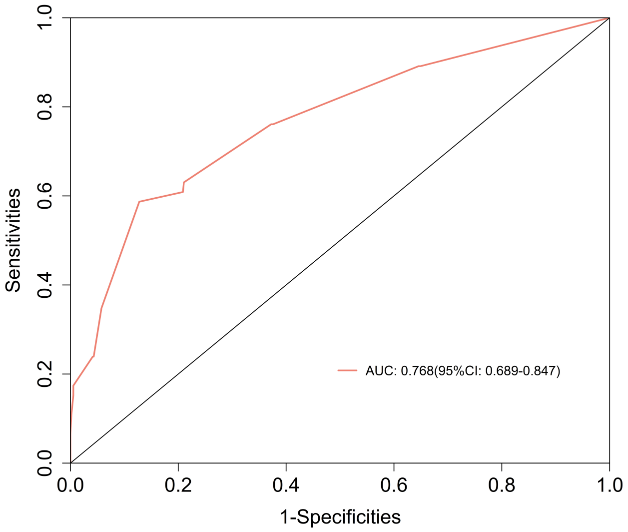

Fig. 1. Receiver operating characteristic curve showing the performance of a single uterine fibroid diameter for predicting postpartum hemorrhage. Note: The X-axis shows the proportion of actual negative samples incorrectly predicted as positive. The Y-axis shows the proportion of actual positive samples correctly predicted. The red curve indicates the current model (AUC = 0.768). Optimal threshold: sensitivity = 0.587, specificity = 0.872.

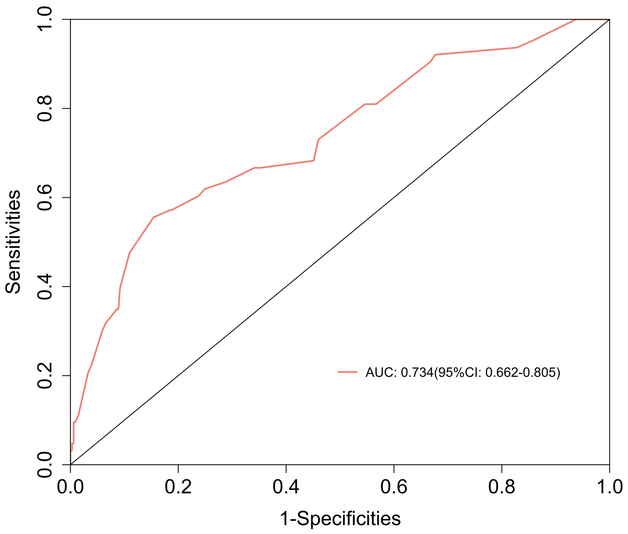

Fig. 2. Receiver operating characteristic curve showing the performance of the sum of the maximum diameters of multiple uterine fibroids for predicting postpartum hemorrhage. Note: The X-axis shows 1-specificity (false positive rate), which indicates the proportion of actual negative samples incorrectly predicted as positive. The Y-axis shows sensitivity (true positive rate), which indicates the proportion of actual positive samples correctly predicted. The red curve indicates the current model (AUC = 0.734). Optimal threshold: sensitivity = 0.556, specificity = 0.846.

3.5 Conditional Logistic Regression Analysis of the Effect of Pre-myomectomy Interventions on PPH

Performing bilateral uterine artery ligation before myomectomy (OR, 0.175; 95% CI, 0.052–0.591; $p < 0.01$) and using potent uterotonic drugs (OR, 0.175; 95% CI, 0.069–0.440; $p < 0.001$) were independent factors that protected against PPH (Table 10).

4. Discussion

The limited research on the association between cesarean myomectomy and PPH has added an extra burden to obstetricians in clinical management. This study showed that the diameter of individual uterine fibroids was a risk factor for PPH, particularly those with a diameter >7.5 cm. A previous study supports this finding. Large fibroids are frequently associated with aberrant vascular proliferation. The resection of these fibroids necessitates a larger myometrial incision, which disrupts uterine wall integrity and expands the exposed vascular surface area, thereby increasing the likelihood of PPH. Some studies have suggested that the removal of fibroids >5 cm during cesarean section is associated with increased intraoperative blood loss and should be approached with caution [18]. By contrast, other studies used 7 cm as the threshold [19]. The variation in the cutoff diameter for predicting PPH may be closely related to our hospital's proactive management of cesarean myomectomy and the skilled techniques of the surgeons, which play a major role in reducing the risk of PPH.

Multiple uterine fibroids were an independent risk factor for PPH in this study. Multifocal fibroids destroy the gap junctions between uterine smooth muscle cells, weakening their ability to contract synchronously. Specifically, in our study, a sum of the maximum diameters of the fibroids exceeding 14.5 cm had good predictive value for PPH, which is slightly different from a finding by Li *et al.* [18]. They found that the number of fibroids has no effect on the risk of PPH. Lee *et al.* [20] found that larger (>10 cm) and heavier (>500 g) fibroids were associated with complications after cesarean myomectomy, whereas the number or type of fibroids was not. They also noted that while multiple fibroids were independently associated with bleeding at delivery, they were not associated with PPH (≥1000 mL), and there was no significant correlation between the maximum diameter of multiple uterine fibroids and PPH. This difference between studies may be due to differences in patients' characteristics between the studies. Our study included women with at least one fibroid with a diameter ≥4 cm, and this was measured during surgery. By contrast, the minimum diameter in a study by Andreani *et al.* [21] was 5 cm, which was determined on preoperative ultrasonography. Therefore, they may have missed fibroids that grew rapidly late in pregnancy. Consequently, further research examining the association between the sum of the maximum diameters of multiple uterine fibroids and PPH is warranted.

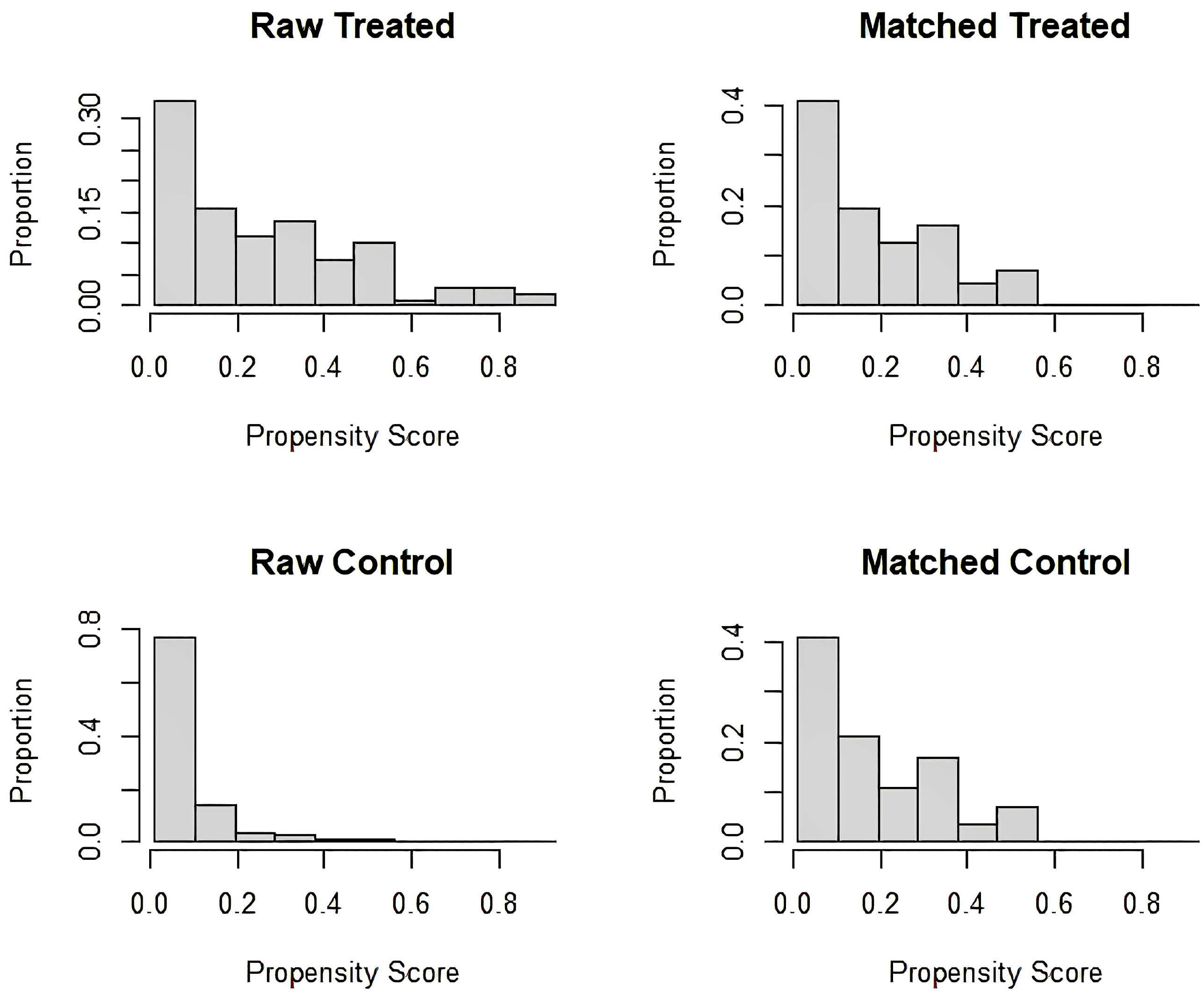

Fig. 3. Distribution of propensity scores in the postpartum hemorrhage and non-postpartum hemorrhage groups before and after propensity score matching. Note: "Raw treated" and "raw control" refer to the data before matching. The substantial overlap deviation indicates baseline covariate imbalances. "Matched treated" and "matched control" refer to the data after matching. Post-matching distributions are shown after 1:3 propensity score matching (caliper = 0.03). "Matched treated" and "matched control" show improved distributional alignment, reflecting effective mitigation of confounding variables through the matching process.

We also found that particular fibroid locations were an independent risk factor for PPH, possibly because of differences in uterine contraction and vascularity. The lower uterine segment is predominantly composed of longitudinal muscle fibers and it shows weaker contractility than the circular myometrial layers of the fundal region. This architectural disparity predisposes this area to localized uterine atony after fibroid resection. Furthermore, the dual blood supply of the uterine segment from the cervical-vaginal arteries creates rich anastomotic vasculature, posing challenges in achieving complete hemostasis during surgery, which is in contrast to the fundal region's singular uterine arterial supply. This partially aligns with the findings of Kwon *et al*. [13], who studied cesarean myomectomy for intramural fibroids. They reported that lower segment fibroids and those with a diameter $\geq$8 cm are independent risk factors for operative bleeding. They also suggested that myomectomy may be considered at the time of cesarean section if fibroids are located in the fundus or body of the uterus and have a diameter $<$8 cm. Therefore, removal of fibroids at particular sites, such as those located at sites predisposed to developing PPH, should be avoided at the time of cesarean section.

Akbaba and Kilicci [22] demonstrated that bilateral uterine artery ligation reduced intraoperative blood loss in patients who underwent laparoscopic and open myomectomy. Furthermore, Hiratsuka *et al*. [23] reported that temporary uterine artery occlusion decreased hemorrhage during laparoscopic myomectomy. Although these studies confirmed the value of uterine artery ligation in reducing hemorrhage from non-pregnant uteri, the underlying mechanism (reducing uterine artery perfusion pressure) may also apply to cesarean myomectomy. The propensity score-matched analysis in our study indicated that bilateral uterine artery ligation before myomectomy protected against PPH in cesarean myomectomy. Several studies have shown that using potent uterotonic agents during abdominal myomectomy can reduce intraoperative blood loss [24,25]. However, research on whether the use of these agents before cesarean myomectomy truly protects against PPH is relatively limited. Our study suggested that using uterotonic agents before cesarean myomectomy protected against PPH. In patients undergoing cesarean myomectomy who have a high risk of PPH, bilateral uterine artery ligation or the administration of potent uterotonic agents before myomectomy can considerably reduce intraoperative blood loss, lower the incidence of PPH, and decrease the occurrence of severe complications.

Our findings provide critical guidance for the prevention and management of PPH during cesarean myomectomy. When investigating PPH in this context, preventative strategies are important, particularly for patients with multiple fibroids or fibroids in certain locations, and for those whose operation time is expected to be prolonged. Meticulous surgical management is crucial in these cases, and procedures should ideally be performed by experienced obstetricians to ensure rapid suturing and to minimize the length of the operation.

To further mitigate the risk of PPH, bilateral uterine artery ligation should be strongly considered, especially for patients at high risk. This intervention reduces blood flow to the uterus, thereby decreasing the likelihood of excessive intraoperative bleeding. Additionally, the use of potent uterotonic drugs is highly recommended to enhance uterine contractions and promote hemostasis after delivery. These preventive measures should be considered critical components of the surgical plan because they greatly contribute to reducing the incidence of PPH and improving patients' outcomes.

This study has several limitations. As a retrospective, single-center, non-randomized analysis, it was susceptible to selection and information biases. Although we attempted to control for confounders using PSM and other statistical methods, confounding may still have been present. Therefore, large-scale, multicenter, prospective studies with diverse patient populations are required. A multi-indicator predictive model should be a key focus of future prospective studies to further refine risk stratification.

5. Conclusions

Independent risk factors for PPH following cesarean myomectomy include multiple fibroids, fibroids in certain locations, and a prolonged duration of surgery. A fibroid diameter $>$7.5 cm in patients with a single fibroid and a sum of diameters $>$14.5 cm in those with multiple fibroids are also independent risk factors. Bilateral uterine artery ligation and the administration of potent uterotonics during this procedure considerably reduce the risk of PPH.

Availability of Data and Materials

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

Author Contributions

XW: methodology, validation, formal analysis, investigation, data curation, writing-original draft; DZ: conceptualization, resources, writing-original draft, project administration, writing-review & editing, supervision; QS: validation, resources, formal analysis, investigation, data curation; XY: writing-review & editing,reviewing it critically for important intellectual content, supervision; HC: Conceptualization (retrospective study design), methodology (outcome definition and interpretation), writing – review & editing, supervision (data validation and methodological oversight). All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Shenyang Women's and Children's Hospital (Approval Number: 202358). All data were fully anonymized. The requirement for informed consent was waived owing to the study's retrospective design.

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Conflict of Interest

The authors declare no conflict of interest.

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