Am J Transl Res 2026;18(8):6807-6822
www.ajtr.org /ISSN:1943-8141/AJTR0172819

Original Article

Influencing factors of general anesthesia and spinal anesthesia for cesarean section women with PAH

Jinlian Ai[1], Rong Liu[1], Hanliang Jiang[2], Nanyan Xi[1]

[1]Department of Anesthesiology, Yingtan 184 Hospital, China Rong Tong Medical Healthcare Group Co., Ltd., Yingtan 335000, Jiangxi, China; [2]Department of Anesthesiology, The First Affiliated Hospital of Changsha Medical University, Changsha 410219, Hunan, China

Received March 22, 2026; Accepted June 26, 2026; Epub August 15, 2026; Published August 30, 2026

Abstract: Objective: To compare the clinical efficacy and safety of general anesthesia versus spinal anesthesia for cesarean section in parturients with pulmonary arterial hypertension (PAH), and analyze the influencing factors for postoperative adverse outcomes. Methods: A retrospective cohort study was conducted on 236 PAH parturients who underwent cesarean section from January 2022 to December 2024. All subjects were grouped via propensity score matching into the general anesthesia group (Group A, n=104) and the spinal anesthesia group (Group B, n=132). Intraoperative hemodynamic parameters, surgical indicators, postoperative adverse events, and neonatal outcomes were compared between the two groups. Subgroup analysis, univariate and multivariate Logistic regression analyses, receiver operating characteristic (ROC) curve analysis, and forest plot analysis were performed for statistical evaluation. Results: At time points T1 to T3, Group B presented significantly lower mean arterial pressure and heart rate with milder hemodynamic fluctuations, less intraoperative blood loss, and a lower overall incidence of adverse events than Group A (all P<0.05). In subgroups of severe PAH and New York Heart Association (NYHA) class III-IV cardiac function, Group B also showed a reduced adverse event rate (P<0.05). Multivariate Logistic regression analysis identified preoperative NYHA classification, anesthesia modality, PAH severity, and preoperative hemoglobin level as independent influencing factors for postoperative adverse outcomes (all P<0.05). ROC curve analysis demonstrated that the combined detection of the above three core indicators yielded superior predictive efficacy compared with single-index detection (P<0.05). The ROC curve of the validation group had an area under the curve (AUC) of 0.739, indicating favorable predictive performance of the model. The calibration curve verified excellent calibration capability, with predicted values highly consistent with actual clinical outcomes. The decision curve analysis showed that the nomogram model maintained positive net clinical benefits within a probability threshold range of 10-90%. Conclusion: Spinal anesthesia provides safer and more stable perioperative hemodynamic conditions for PAH parturients undergoing cesarean section. The combined evaluation of preoperative clinical indicators can effectively predict postoperative adverse outcomes in this patient population.

Keywords: General anesthesia, spinal anesthesia, pulmonary arterial hypertension, cesarean section, clinical outcome

Introduction

Pulmonary arterial hypertension (PAH) is a severe hemodynamic and pathophysiological disorder characterized by progressive elevation of pulmonary artery pressure and increased pulmonary vascular resistance [1]. Epidemiological data [2, 3] indicate that the global incidence of PAH is approximately 9.7 per 100,000 population, with a disproportionate prevalence among pregnant women. The maternal mortality rate of PAH-complicated pregnancy ranges from 30% to 56%, representing a critical high-risk obstetric condition. Pregnancy induces a series of physiological hemodynamic changes, including increased intravascular volume, elevated cardiac output, and reduced pulmonary vascular resistance. However, PAH disrupts this adaptive physiological balance, significantly increasing right ventricular afterload and cardiac burden, and further triggering severe complications such as right heart failure and refractory hypoxemia [4].

Cesarean delivery can terminate pregnancy rapidly, avoid sustained hemodynamic fluctua-

https://doi.org/10.62347/XECE9153

tions induced by prolonged uterine contractions, and reduce oxygen consumption caused by labor fatigue and pain, thus serving as the primary delivery modality for PAH-complicated pregnant women. Nevertheless, surgical trauma, intravascular volume shifts, and sympathetic nervous system activation during cesarean section may precipitate acute spikes in pulmonary artery pressure and exacerbate cardiopulmonary dysfunction [5]. Therefore, the selection of an appropriate anesthesia method is critical to surgical success and maternal-neonatal prognosis in PAH parturients.

General anesthesia, administered via intravenous or inhalation routes, features rapid anesthesia induction, complete muscle relaxation, and reliable airway control [6]. Neuraxial anesthesia blocks spinal nerve conduction by local anesthetic injection into the spinal canal, suppresses surgical stress responses, reduces the release of vasoactive substances such as catecholamines, and maintains stable systemic vascular resistance [7]. At present, high-quality evidence regarding the comparative efficacy and clinical outcomes of these two anesthesia modalities in PAH parturients undergoing cesarean section remains insufficient. Most previous studies only compared the overall clinical effects of the two methods, without conducting stratified subgroup analysis based on PAH severity and cardiac function grading, nor constructing and validating a multi-index combined prediction model for adverse postoperative outcomes. In view of the above research gaps, this study performed subgroup analysis on the basis of comparative evaluation of anesthetic effects, and established and validated a combined predictive model, aiming to explore the clinical application value of general and spinal anesthesia in cesarean section for PAH parturients and identify key influencing factors of clinical outcomes.

Materials and methods

Study population

This retrospective cohort study enrolled 236 PAH parturients who underwent cesarean section from January 2022 to December 2024. All participants were stratified via propensity score matching into Group A (general anesthesia, n=104) and Group B (spinal anesthesia, n=132), **Figure 1**. This study was approved by the Ethics Committee of Yingtan 184 Hospital. Given the retrospective study design, the requirement for written informed consent was waived by the ethics committee.

Inclusion criteria: (1) Resting pulmonary artery systolic pressure (PASP) ≥30 mmHg confirmed by echocardiography, with PAH severity graded in accordance with the European Society of Cardiology (ESC) pulmonary hypertension guidelines [8]: mild (PASP 30-49 mmHg), moderate (PASP 50-79 mmHg), and severe (PASP≥80 mmHg); (2) Singleton pregnancy with elective or emergency cesarean delivery performed in our hospital; (3) American Society of Anesthesiologists (ASA) physical status class I-III [9]; (4) No history of severe psychiatric disorders.

Exclusion criteria: (1) Complicated with severe failure of vital organs including the heart, liver and kidney; (2) Presence of absolute or relative contraindications to spinal or general anesthesia; (3) Complicated with gestational hypertension disorder, gestational diabetes mellitus or other pregnancy-specific complications; (4) Complicated with autoimmune diseases such as systemic lupus erythematosus; (5) Combined with coagulation dysfunction or other hematological diseases; (6) Complicated with infectious diseases such as hepatitis B.

Sample size calculation was performed using PASS 15.0 software. Based on a previously reported 30% incidence of adverse events in PAH parturients undergoing cesarean section [1], with a significance level of $\alpha=0.05$ and statistical power of $1-\beta=0.8$, the minimum required sample size was calculated as 220 cases. A total of 236 cases were finally enrolled, which met the statistical power requirement.

Anesthetic and perioperative management

All non-emergency parturients received multidisciplinary joint consultation involving cardiology, cardiac surgery, obstetrics, anesthesiology and respiratory medicine 24 hours preoperatively to optimize cardiac function with targeted pharmacological and supportive interventions. After entering the operating room, routine oxygen inhalation was administered, and continuous monitoring of electrocardiography, non-invasive blood pressure, respiratory rate and peripheral oxygen saturation was performed. Radial artery puncture and catheterization

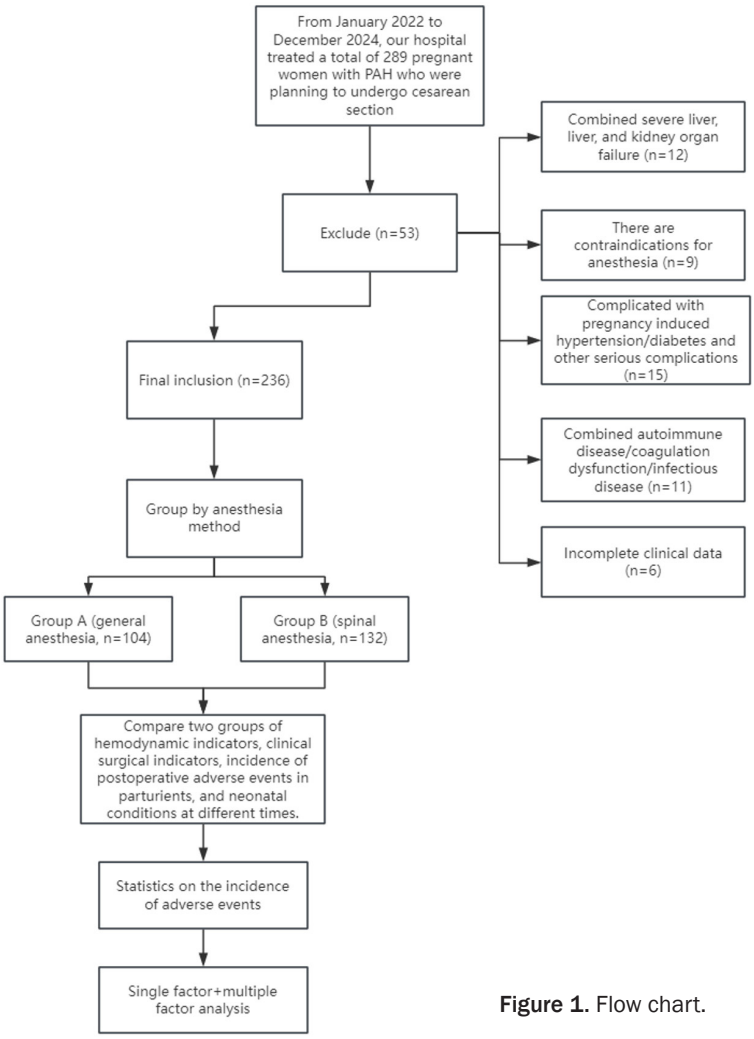

Figure 1. Flow chart.

were performed under local anesthesia for invasive arterial pressure monitoring, and baseline blood gas analysis was conducted to evaluate maternal oxygenation status.

Group A (General anesthesia): After surgical disinfection and draping, local anesthetics were applied before skin incision to reduce surgical stress. The operating table was adjusted to a head-up and foot-down position. Anesthesia was induced with etomidate or propofol combined with rocuronium bromide. Rapid sequence tracheal intubation was performed with low tidal volume ventilation combined with the Sellick maneuver, followed by pure oxygen controlled mechanical ventilation during surgery. Continuous sevoflurane inhalation (Shanghai Hengrui Pharmaceutical; specification: 120 ml; approval number: H20070172) was maintained intraoperatively, and 0.1-0.2 mg fentanyl was administered after fetal delivery.

Group B (Spinal anesthesia): Parturients were placed in the left lateral decubitus position, and lumbar puncture was performed at the L3-L4 interspace. After free flow of cerebrospinal fluid was confirmed, 1.4-1.6 ml of heavy bupivacaine solution (0.75% bupivacaine 1.2-1.4 ml + 50% glucose injection 0.2 ml; Hunan Zhengqing Pharmaceutical; specification: 5 ml:12.5 mg; NMPA approval number: H43021019) was slowly injected, and an epidural catheter was inserted cephalad. The anesthesia level was strictly controlled below the T6 dermatome, and supplementary local anesthetics were administered dynamically according to maternal vital signs and surgical progress. Individualized dosing regimens were adopted based on PAH severity: 1.6 ml for mild PAH, 1.4 ml for moderate PAH, and 1.2 ml for severe PAH.

Intraoperative fluid and vasoactive drug management: Goal-directed fluid therapy (GDFT) was implemented in both groups. Pulse contour analysis was used to monitor stroke volume variation (SVV), with SVV<13% defined as the target for fluid resuscitation. Lactated Ringer's solution was used as the crystalloid fluid with a baseline infusion rate of 10-15 mL/(kg·h), which was dynamically adjusted based on SVV values: 200 mL crystalloid bolus infusion for SVV of 13-20% with SVV monitoring every 15 minutes; 100 mL hydroxyethyl starch colloid bolus infusion for SVV>20%, repeated until SVV<13% (maximum daily colloid dosage ≤1000 mL/24 h). Intraoperative fluid intake and output (urine volume, intraoperative blood loss) were strictly recorded to maintain negative or mild positive fluid balance (<500 mL). Stratified fluid management was performed according to PAH severity: SVV was maintained at 10-13% for mild PAH and 8-10% for moder-

Table 1. Comparison of general information between the two groups [($\bar{x}$±sd), *n* (%)]

Variables	Group A (*n*=104)	Group B (*n*=132)	χ^2/t	*P* (After correction)
Age (years)	28.86±3.68	29.14±3.72	0.577	0.564
BMI (kg/m^2)	25.42±3.12	25.22±3.24	0.479	0.633
Place of residence			0.133	0.715
Town	59 (56.73)	78 (59.09)		
Rural area	45 (43.27)	54 (40.91)		
ASA classification			0.641	0.423
Class II	66 (63.46)	77 (58.33)		
Class III	38 (36.54)	55 (41.67)		
Gestational age (week)	33.46±2.73	33.19±2.52	0.788	0.432
Delivery times (times)	1.31±0.33	1.28±0.31	0.717	0.474
Pregnancy induced hypertension	39 (37.50)	42 (31.82)	0.833	0.361
Gestational diabetes	35 (33.65)	38 (28.79)	0.645	0.422
Preoperative pulmonary artery pressure			0.002	0.965
Mild to moderate	73 (70.19)	93 (70.45)		
Severe	31 (29.81)	39 (29.54)		

Note: BMI: Body Mass Index; ASA: American Society of Anesthesiologists; NYHA: New York Heart Association; PAH: pulmonary arterial hypertension; The *P* values were obtained after multiple comparison correction using the Bonferroni method.

Table 2. Comparison of mean arterial pressure between the two groups of patients at different time points ($\bar{x}$±sd, mmHg)

Group	Number of cases	T0	T1	T2	T3
Group A	104	93.79±8.42	91.57±7.19	102.57±8.09	101.57±7.95
Group B	132	93.45±8.36	90.93±7.23	97.85±7.72	94.85±7.53
F_{time}, P_{time}			97.216, <0.001		
$F_{Inter\ group}$, $P_{Inter\ group}$			37.904, <0.001		
$F_{time\times group}$, $P_{time\times group}$			17.896, <0.001		

Note: MAP: mean arterial pressure.

Table 3. Comparison of heart rate of the two groups of patients at different time nodes ($\bar{x}$±sd, Times/min)

Group	Number of cases	T0	T1	T2	T3
Group A	104	81.79±4.42	73.57±3.29	75.57±3.33	77.79±4.02
Group B	132	81.05±4.19	75.93±3.35	79.95±3.52	80.65±4.07
F_{time}, P_{time}			445.862, <0.001		
$F_{Inter\ group}$, $P_{Inter\ group}$			63.814, <0.001		
$F_{time\times group}$, $P_{time\times group}$			119.249, <0.001		

Note: HR: heart rate.

ate to severe PAH, with fluid balance strictly controlled below 300 mL negative balance.

Vasoactive drugs were administered per standardized criteria: (1) Norepinephrine: intravenous infusion at 0.05-0.2 μg/(kg·min) when systolic blood pressure dropped by more than 20% from baseline; (2) Dopamine: intravenous infusion at 5-10 μg/(kg·min) in the presence of decreased cardiac output; (3) Milrinone: loading dose of 50 μg/kg followed by maintenance infusion at 0.375-0.75 μg/(kg·min) for heart failure. No significant intergroup differences were observed in the usage rate and average dosage of norepinephrine (Group A: 38.46% [40/104], 0.12±0.04 μg/(kg·min); Group B: 32.58% [43/132], 0.10±0.03 μg/(kg·min)), dopamine or milrinone (all P>0.05).

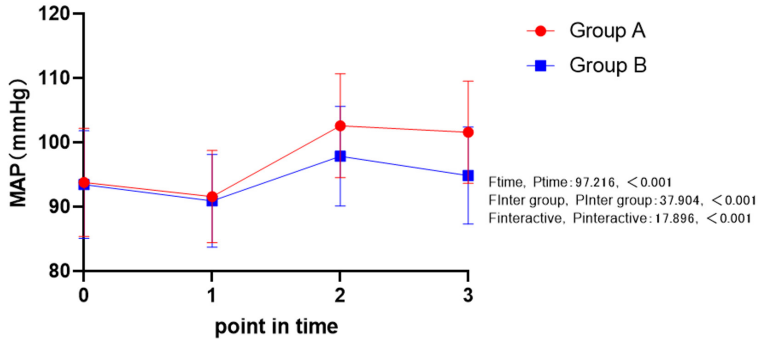

Figure 2. Comparison of mean arterial pressure between the two groups of patients at different time points. Note: Repeated-measures ANOVA revealed significant main effects of time (Ftime=97.216, *P*<0.001), group (Finter group=37.904, *P*<0.001), and a significant time-group interaction (Finteractive=17.896, *P*<0.001).

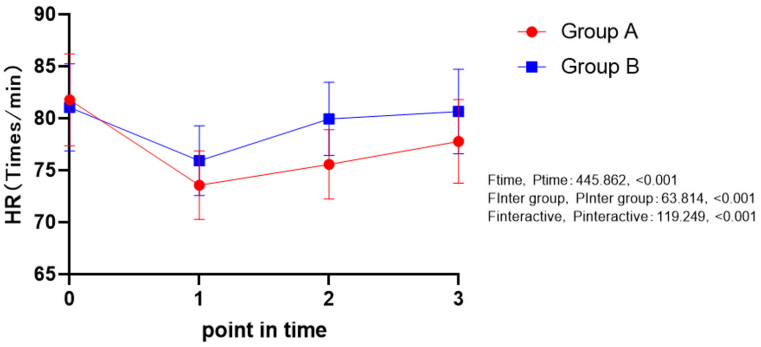

Figure 3. Comparison of heart rate of the two groups of patients at different time nodes. Repeated measures ANOVA showed that the time main effect (*F*=445.862, *P*<0.001), inter group main effect (*F*=63.814, *P*<0.001), and interaction effect (*F*=119.249, *P*<0.001) were all statistically significant.

Table 4. Comparison of clinical surgical indicators between the two groups of parturients ($\bar{x}$±sd)

Group	Number of cases	Intraoperative bleeding volume (ml)	hospital stay (d)	Newborn Apgar score (points)
Group A	104	297.17±20.19	10.08±2.43	7.77±0.82
Group B	132	290.54±18.73	9.66±2.27	7.80±0.84
t-values		2.608	1.335	0.275
P-values		0.009	0.183	0.783

Perioperative blood pressure was stabilized with norepinephrine and dopamine. Milrinone or digoxin was administered for heart failure, with strict fluid restriction and furosemide supplementation if necessary. The anesthesia modality for each patient was jointly determined by a multidisciplinary team consisting of obstetricians, anesthesiologists and cardiologists based on standardized criteria: (1) Spinal anesthesia was the preferred choice for elective cesarean section parturients with no spinal anesthesia contraindications and mild-to-moderate PAH; (2) General anesthesia was selected for parturients with spinal anesthesia contraindications or severe PAH; (3) For emergency cesarean section (e.g., fetal distress), the attending anesthesiologist determined the anesthesia modality based on on-site maternal condition evaluation. Propensity score matching was applied to balance baseline characteristics and ensure intergroup comparability.

Outcome measures

(1) Hemodynamic parameters: Heart rate (HR) and mean arterial pressure (MAP) of all parturients were recorded at four time points: pre-anesthesia induction (T0), 30 minutes after surgical initiation (T1), immediately after fetal delivery (T2), and postoperatively (T3).

(2) Surgical clinical indicators: Intraoperative blood loss, postoperative hospital stay, and 1-minute neonatal Apgar score were compared between the two groups.

(3) Postoperative adverse events: The observation period for adverse events covered the entire perioperative period to 30 days postoperatively (perioperative period defined as from anesthesia induction to 24 hours after surgery completion). Major adverse cardiovascular and neonatal events including all-cause mortality, myocardial infarction, respiratory failure, arrhythmia, thrombotic events, and neonatal asphyxia were recorded in both groups. Adverse event diagnoses were based on the ESC Guidelines for the Management of Cardiovascular Diseases in Pregnancy [10]: ① Myocardial infarction: troponin I>0.04 ng/mL accompanied by chest pain and ST-T segment abnormalities on electrocar-

Table 5. Comparison of postoperative adverse events between the two groups [*n* (%)]

Group	Number of cases	death	myocardial infarct	respiratory failure	Arrhythmia	thrombus	Neonatal asphyxia	Total incidence rate
Group A	104	4 (3.85)	7 (6.73)	5 (4.81)	8 (7.69)	6 (5.77)	7 (6.73)	37 (35.58)
Group B	132	2 (1.52)	8 (6.06)	3 (2.27)	7 (5.30)	5 (3.79)	5 (3.79)	30 (22.73)
χ^2-values								4.724
P-values								0.029

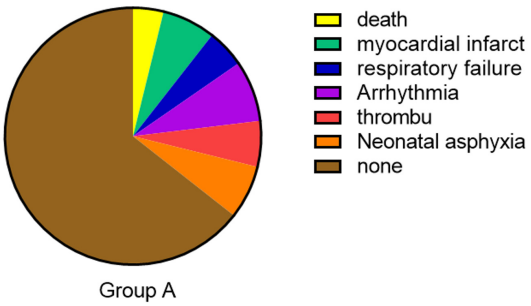

Figure 4. Postoperative adverse events in group A.

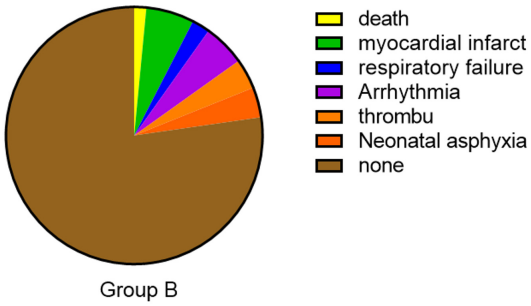

Figure 5. Postoperative adverse events in group B.

diography; ② Thrombotic events: venous or arterial thrombosis confirmed by ultrasound or CTA imaging; ③ Arrhythmia: ventricular premature beats >5 beats per minute, atrial fibrillation, ventricular tachycardia or other malignant arrhythmias confirmed by electrocardiography; ④ Neonatal asphyxia: 1-minute Apgar score <7 points [11]; ⑤ All-cause mortality: death occurring within 30 days postoperatively.

(4) Univariate analysis of adverse clinical outcomes: All enrolled parturients were divided into adverse event and non-adverse event groups according to the occurrence of postoperative adverse outcomes. Baseline variables including age, BMI, educational level, residence, gestational age, gravidity, parity, preoperative HR, ASA classification, New York Heart Association (NYHA) cardiac function class, preoperative pulmonary artery pressure, neonatal weight, and laboratory indicators were compared. Preoperative venous blood samples (5 mL) were centrifuged at 3000 r/min for 15 min (centrifugation radius: 10 cm). A fully automatic hematology analyzer (Mindray BC-20s) was used to detect hemoglobin levels; a chemiluminescence immunoassay analyzer (Mindray CL-2600i) was used to detect serum electrolyte levels; a fully automatic biochemical analyzer (Boke BK-1200) was used to detect serum total cholesterol and triglyceride levels. The Bonferroni method was used for multiple comparison correction, with P<0.05 defined as statistically significant to screen potential risk factors for adverse outcomes.

(5) Multivariate logistic regression analysis: Variables with significant differences in univariate analysis after Bonferroni correction were included in the multivariate Logistic regression model. With postoperative adverse events as the dependent variable, stepwise regression was adopted to screen independent influencing factors, and odds ratios (OR) and 95% confidence intervals (CI) were calculated to quantify the correlation between each factor and adverse outcomes.

Statistical methods

All statistical analyses were performed using SPSS 26.0 and GraphPad Prism 8.0 software. Baseline enumeration data were expressed as cases (percentage) and compared using the Pearson χ^2 test or Fisher's exact test as appropriate. Continuous data were tested for normality via the Shapiro-Wilk test; normally distributed data were presented as mean ± standard deviation ($\bar{x}\pm sd$) and compared using the independent samples t-test. Repeated-measures ANOVA was used to analyze the time-dependent and group-dependent differences in hemodynamic parameters (MAP, HR) at T0-T3. Intraoperative surgical indicators were compared via independent samples t-test. The incidence of adverse events was compared using

Table 6. Subgroups of different PAH grades ($\bar{x}$±sd)

Subgroup	Group	*n*	Adverse event	χ^2	*P*
Moderate PAH	Group A	73	15 (20.55)	1.755	0.185
	Group B	93	12 (12.90)		
Severe PAH	Group A	31	22 (70.97)	4.342	0.037
	Group B	39	18 (46.15)		

Note: PAH: pulmonary arterial hypertension.

Table 7. Subgroups of different concentric functional classifications ($\bar{x}$±sd)

Subgroup	Group	*n*	Adverse event	χ^2	*P*
NYHA I-II	Group A	68	12 (17.65)	0.028	0.868
	Group B	102	17 (16.67)		
NYHA III-IV	Group A	36	25 (69.44)	4.342	0.037
	Group B	30	13 (43.33)		

Note: NYHA: New York Heart Association.

the χ^2 test with Bonferroni multiple comparison correction to control type I error.

Subgroup analyses, stratified by PAH severity and NYHA classification, were performed. Variables with P<0.05 in univariate analysis were incorporated into the forward stepwise multivariate logistic regression model to screen independent risk factors. The forced entry method was used to establish the regression model after adjusting for baseline confounding factors. Variance inflation factor (VIF) was calculated to assess multicollinearity, with VIF<2 indicating no significant multicollinearity.

ROC curve analysis was performed to evaluate the predictive efficacy of single indicators and the combined model, with AUC values compared via the DeLong test. Bootstrap resampling (1000 iterations) was used for internal validation of the combined prediction model. Calibration curves and decision curve analysis (DCA) were plotted to evaluate the calibration degree and clinical net benefit of the model. A two-tailed P<0.05 was considered statistically significant for all statistical tests.

Results

Comparison of clinical data

Baseline clinical data were well-balanced between the two groups with no statistically significant differences (P>0.05), as summarized in **Table 1**.

Comparison of hemodynamic parameters at different time points

At T1, T2 and T3, Group B had significantly lower MAP and HR with milder hemodynamic fluctuations than Group A (all P<0.05). No significant intergroup differences in MAP and HR were observed at the T0 baseline time point (both P>0.05) (**Tables 2**, **3**; **Figures 2**, **3**).

Comparison of surgical clinical indicators

Group B had significantly less intraoperative blood loss than Group A (P<0.05). No significant difference in postoperative hospital stay was found between the two groups (P>0.05) (**Table 4**).

Comparison of postoperative adverse events

The overall incidence of postoperative adverse events in Group B was significantly lower than that in Group A (P<0.05) (**Table 5**; **Figures 4**, **5**).

Subgroup analysis

In the severe PAH subgroup, the adverse event rate of Group B was significantly lower than that of Group A (P<0.05) (**Table 6**).

In the NYHA III-IV subgroup, Group B exhibited a significantly lower adverse event rate than Group A (P<0.05) (**Table 7**).

Univariate analysis of postoperative adverse outcomes

According to the occurrence of postoperative adverse events, 236 parturients were divided into the good (*n*=169) and poor groups (n=67). The poor group had significantly higher maternal age and BMI, higher proportions of NYHA III-IV grade, general anesthesia application and severe preoperative PAH, and significantly lower preoperative hemoglobin levels (all P<0.05) (**Table 8**).

Multivariate logistic regression analysis of adverse outcomes

All variables with statistical significance in univariate analysis were included in the multivari-

Table 8. Univariate analysis of adverse clinical outcomes [($\bar{x}$±sd), *n* (%)]

Variables	poor group (*n*=67)	good group (*n*=169)	χ^2/t	*P* (after correction)
Age (years)	29.27±3.44	28.26±2.82	2.326	0.021
BMI (kg/m^2)	26.32±3.36	25.26±3.11	2.307	0.022
Degree of education			0.124	0.725
High school or below	35 (52.24)	84 (49.70)		
College degree or above	32 (47.76)	85 (50.30)		
Place of residence			0.068	0.794
Town	38 (56.72)	99 (58.58)		
Rural area	29 (43.28)	70 (41.42)		
Gestational age (week)	33.27±2.52	33.35±2.49	0.222	0.825
Pregnancy times (times)	2.09±0.42	2.11±0.43	0.324	0.746
Delivery times (times)	1.41±0.30	1.38±0.29	0.710	0.478
Pregnancy induced hypertension	26 (38.81)	55 (32.54)	0.834	0.361
Gestational diabetes	19 (28.36)	54 (31.95)	0.290	0.590
Heart rate (beats/min)	80.57±4.37	81.02±4.28	0.724	0.469
ASAclassification			0.589	0.443
Class II	38 (56.72)	105 (62.13)		
Class III	29 (43.28)	64 (37.87)		
Preoperative NYHA classification			5.457	0.019
Class I-II	41 (61.19)	129 (76.33)		
Class III-IV	26 (38.81)	40 (23.67)		
Anesthesia			6.073	0.014
General anesthesia	38 (56.72)	66 (68.60)		
Neuraxial anesthesia	29 (43.28)	103 (31.40)		
Preoperative pulmonary artery pressure			6.598	0.010
Mild to moderate	39 (58.21)	127 (75.15)		
Severe	28 (41.79)	42 (24.85)		
Neonatal weight (g)	3152.70±350.44	3193.27±362.18	0.783	0.434
Hemoglobin (g/L)	117.44±9.82	122.57±10.36	3.480	<0.001
Blood potassium (mmol/L)	3.22±0.61	3.30±0.63	0.887	0.375
Blood sodium (mmol/L)	135.63±5.22	135.48±5.19	0.200	0.842
blood calcium (mmol/L)	2.52±0.18	2.54±0.17	0.801	0.424
Blood phosphorus (mmol/L)	1.33±0.15	1.31±0.14	0.970	0.333
Total cholesterol (mmol/L)	4.63±0.68	4.58±0.66	0.520	0.603
Triglyceride (mmol/L)	1.32±0.26	1.28±0.24	0.845	0.399

Note: BMI: Body Mass Index; ASA: American Society of Anesthesiologists; The *P* values were corrected by Bonferroni method for multiple comparisons.

Table 9. Independent variable assignment

variable	assignment
Age	<30 years old=0, ≥ 30 years old=1
BMI	<24kg/m^2=0.24-28kg/m^2=1, >28kg/m^2=2
Preoperative NYHA classification	Level I-II=0, Level III-IV=1
Anesthesia method	General anesthesia=1, spinal anesthesia=0
Preoperative PAH	Mild to moderate=0, Severe=1
hemoglobin	≥110-=0, <110 g/L=1

Note: BMI: Body Mass Index; NYHA: New York Heart Association; PAH: pulmonary arterial hypertension.

Table 10. Logistic multivariate regression analysis of adverse clinical outcomes

Variable	*B*	*SE*	*Wald*	*P*	*OR*	*95% CI*
Age	0.098	0.054	3.288	0.070	1.103	0.992-1.227
BMI	0.081	0.048	2.877	0.090	1.085	0.987-1.191
Preoperative NYHA classification	1.068	0.399	7.157	0.007	2.909	1.330-6.361
Anesthesia method	1.444	0.394	13.408	<0.001	4.237	1.956-9.178
Preoperative PAH	0.947	0.392	5.843	0.016	2.577	1.196-5.553
Hemoglobin	-0.041	0.015	7.626	0.006	0.960	0.932-0.988

Note: BMI: Body Mass Index; NYHA: New York Heart Association; PAH: pulmonary arterial hypertension.

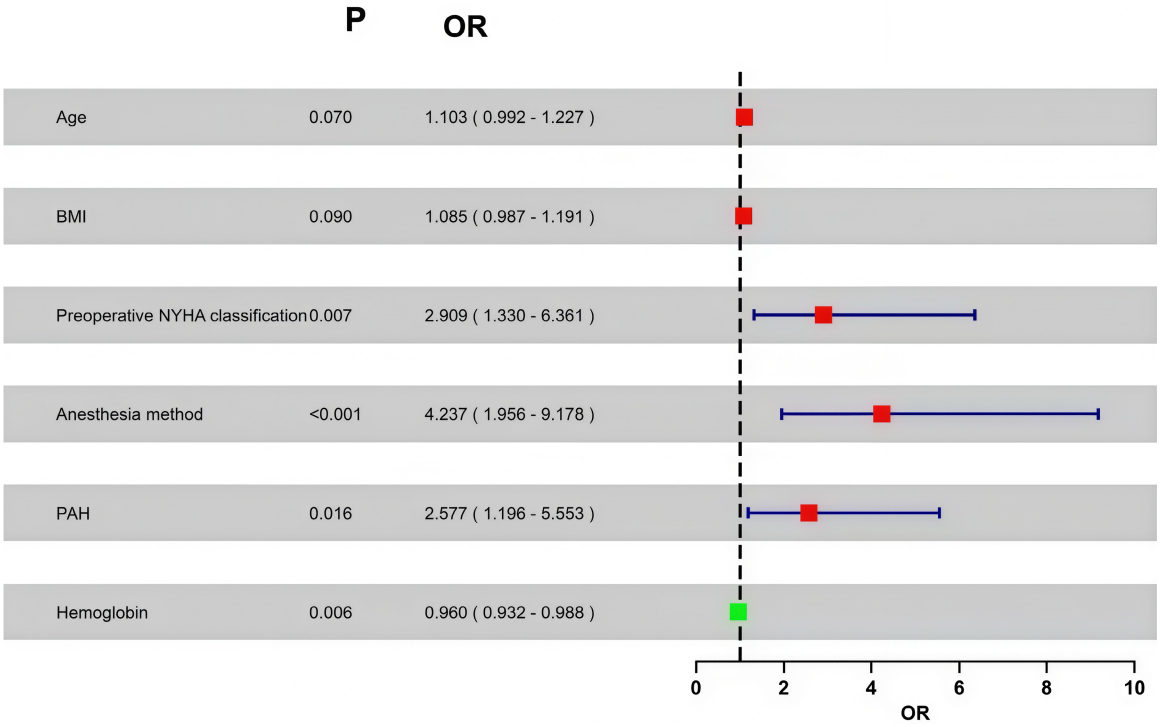

Figure 6. Forest plot of significant variables in Logistic multiple regression. PAH cesarean section. Note: OR>1 is a risk factor for adverse outcomes, while OR<1 is a protective factor; *P*<0.05 indicates a statistically significant difference. PAH: preoperative pulmonary arterial hypertension.

Table 11. The value of relevant indicators in evaluating adverse clinical outcomes after pulmonary arterial hypertension cesarean section

Indicator	AUC	Standard error	95% CI	*P*	cut-off	Youden index	Sensitivity (%)	Specificity (%)
Preoperative NYHA classification	0.622*	0.047	0.529-0.709	<0.001	-	0.245	55.88	68.60
Preoperative PAH	0.679*	0.059	0.588-0.761	0.025	-	0.339	67.65	66.28
Hemoglobin	0.657*	0.059	0.564-0.741	<0.001	≤119.047 g/L	0.281	55.88	73.26
Combine detection	0.853	0.037	0.776-0.911	<0.001		0.626	82.40	80.20

Note: Compared with combine detection, **P*<0.05.

ate logistic regression model. After adjusting for confounding factors including age and BMI, preoperative NYHA classification, anesthesia modality, PAH severity, and preoperative hemoglobin level were identified as independent influencing factors for postoperative adverse outcomes in PAH parturients (all P<0.05) (**Tables 9**, **10**). Multicollinearity verification showed all VIF values <2 (1.465, 1.453, 1.028, 1.019), indicating no multicollinearity among

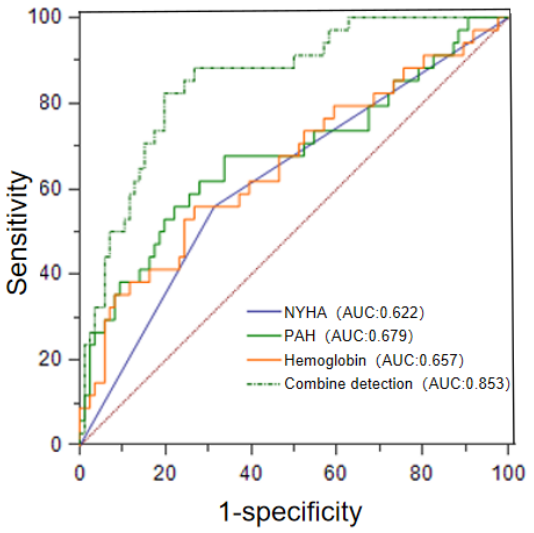

Figure 7. ROC curve of the value of relevant indicators in evaluating adverse clinical outcomes after PAH cesarean section. Note: NYHA: preoperative NYHA classification; PAH: preoperative pulmonary arterial hypertension; The larger the AUC, the higher the predictive value; Joint detection AUC=0.853.

variables. A forest plot was generated based on the OR values of independent influencing factors (**Figure 6**), where OR>1 indicated a positive correlation with adverse event risk, and OR<1 indicated a negative correlation.

Predictive value of preoperative indicators for postoperative adverse outcomes

ROC curve analysis showed that the combined detection of preoperative NYHA classification, PAH severity and hemoglobin level yielded a significantly higher AUC than single-index detection (Z=4.657, 2.947, 3.421, all P<0.05) (**Table 11**; **Figure 7**).

Establishment and validation of the predictive nomogram model

A predictive nomogram model for postoperative adverse outcomes in PAH parturients was constructed based on the three independent influencing factors (preoperative NYHA classification, PAH severity, hemoglobin level), with PAH severity showing the highest predictive weight (**Figure 8**).

The model group included 236 enrolled patients, and an external validation group consisted of 101 PAH parturients who underwent cesarean section in the First Affiliated Hospital of Changsha Medical University from January 2023 to 2025, with consistent inclusion and exclusion criteria.

For the model group, the ROC curve AUC was 0.853, indicating excellent predictive efficacy (**Figure 9**). Bootstrap internal validation (1000 resamples) and calibration curve analysis confirmed favorable model calibration, with predicted values highly consistent with actual outcomes (**Figure 10**). The Hosmer-Lemeshow goodness-of-fit test showed P=0.746, and the average absolute calibration error was 0.018, indicating satisfactory fitting and accuracy.

For the validation group, the ROC curve AUC was 0.739, verifying the stable and reliable predictive performance of the model (**Figure 11**). The calibration curve showed good consistency between predicted and actual values (**Figure 12**), with a goodness-of-fit test P=0.175 and an average absolute calibration error of 0.047.

DCA curves demonstrated that the nomogram model maintained positive net clinical benefits within a wide threshold probability range of 10-90%, confirming good clinical practicability (**Figures 13**, **14**).

Discussion

Pregnancy and PAH interact synergistically to exacerbate cardiopulmonary dysfunction. Pregnancy-related placental hemodynamic remodeling aggravates pulmonary vascular lesions in PAH patients, while PAH-induced chronic hypoxemia adversely affects fetal development, greatly increasing the risks of pregnancy and delivery in this population [12]. General anesthesia eliminates maternal consciousness and surgical pain via intravenous or inhaled anesthetics, enabling rapid intraoperative intervention and ensuring surgical safety especially in emergency scenarios [13]. Spinal anesthesia produces targeted regional anesthesia by blocking spinal nerve conduction in the subarachnoid space, with minimal interference to systemic circulation [14, 15].

This study found that spinal anesthesia could effectively stabilize intraoperative HR and MAP with milder hemodynamic fluctuations, reduce intraoperative blood loss, and lower the incidence of postoperative adverse events compared with general anesthesia. These advan-

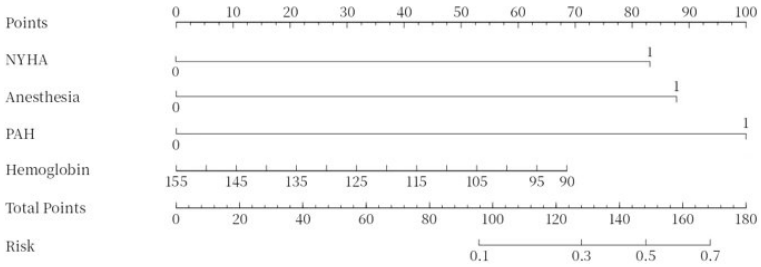

Figure 8. Nomogram for predicting the risk of adverse outcomes after cesarean section in pregnant women with PAH (PAH). Note: The nomogram is constructed based on four independent predictors: preoperative NYHA class, anesthesia method, PAH severity (measured by pulmonary arterial pressure), and hemoglobin level. To estimate the individual risk of postoperative adverse outcomes, the following steps should be performed: Locate the value of each predictor on its corresponding axis and draw a vertical line upward to the "Points" scale to obtain the score for that variable; Sum the scores of all four predictors to derive the total points; Find the total points on the "Total Points" axis, and draw a vertical line downward to the "Risk" axis to read the predicted probability of adverse outcomes.

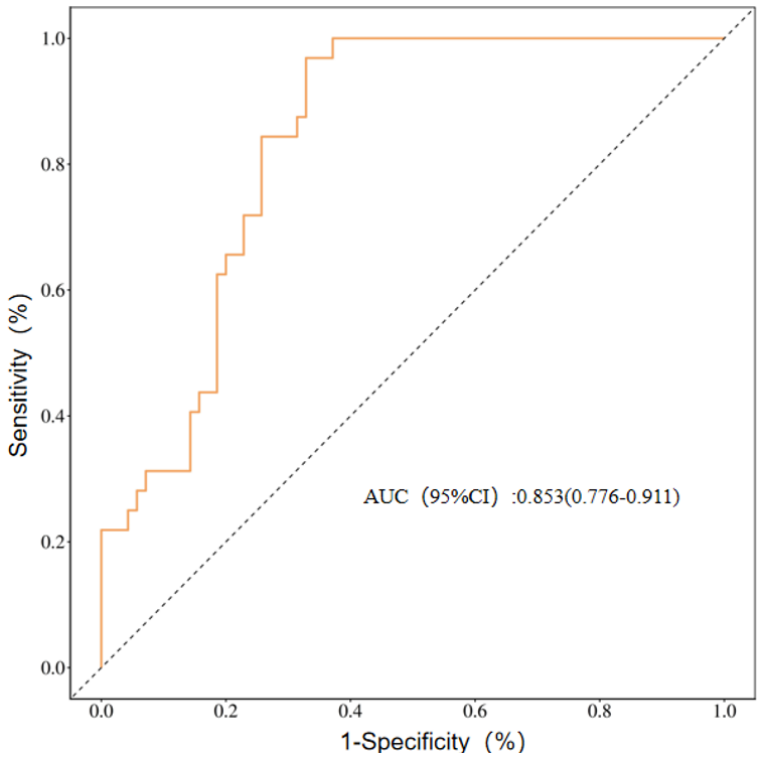

Figure 9. ROC curve of model group. Note: DeLong test: compared with single indicators, $P<0.05$.

tages are attributed to the inherent characteristics of spinal anesthesia: it blocks sympathetic preganglionic fibers to moderately dilate peripheral vessels without inhibiting myocardial contractility, and avoids severe hemodynamic fluctuations caused by general anesthesia induction and tracheal intubation stress [16]. In contrast, general anesthetics directly inhibit myocardial contractility and sympathetic activity; tracheal intubation-induced stress activates the sympathoadrenal axis, leading to acute tachycardia, vasoconstriction and elevated pulmonary artery pressure, which further destabilizes perioperative circulation and increases cardiac burden in PAH parturients [16, 17]. Consistent with the findings of the previous reports [18, 19], this study confirms that spinal anesthesia is superior to general anesthesia in maintaining hemodynamic stability and reducing perioperative adverse events in PAH parturients.

Univariate analysis showed that advanced age, high BMI, advanced NYHA III-IV grade, severe preoperative PAH, general anesthesia application and low preoperative hemoglobin were associated with postoperative adverse events. Further multivariate regression analysis confirmed preoperative NYHA classification, anesthesia modality, PAH severity and hemoglobin level as independent risk factors. Age and BMI showed no independent predictive value after adjusting for confounding factors, indicating that their statistical differences in univariate analysis were attributed to confounding correlations with core indicators.

Parturients with advanced NYHA grade and severe PAH have impaired cardiac reserve and poor tolerance to surgical stress, which easily leads to perioperative cardiac decompensation [20]. Low hemoglobin levels reduce blood oxygen-carrying capacity, inducing systemic hypoperfusion and hypoxemia, impairing myocardial and organ function, and hindering postoperative tissue repair and recovery [21].

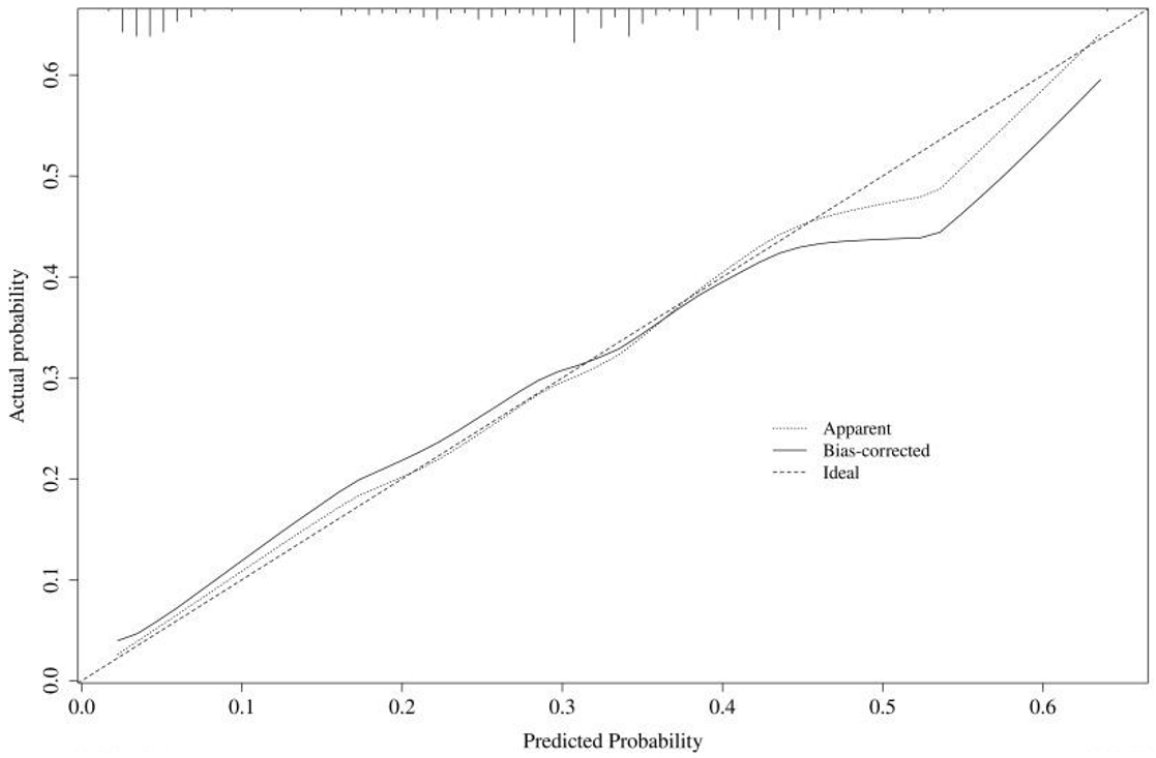

Figure 10. Model group calibration curve. Note: Apparel: apparent prediction; Bias corrected: prediction after correction; Ideal: ideal reference line.

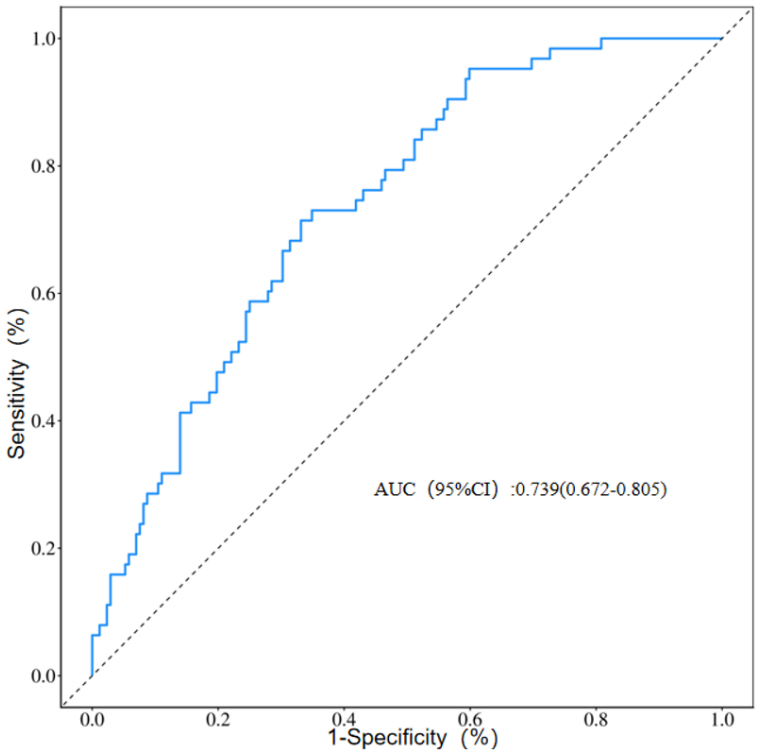

Figure 11. ROC curve of validation group. Note: DeLong test: compared with the model group, $P<0.05$.

Spinal anesthesia reduces perioperative adverse events by suppressing surgical stress, reducing vasoactive substance release and stabilizing pulmonary circulation [22, 23], while general anesthesia-related stress and drug-induced cardiac inhibition exacerbate cardiopulmonary dysfunction in PAH patients [24].

The constructed nomogram model based on the three core indicators exhibited good predictive efficacy in both internal and external validation, with favorable calibration and wide clinical net benefit. All included indicators are routine, easily accessible and quantifiable clinical parameters, conferring high clinical promotion and application value.

In clinical practice, stratified individualized anesthesia

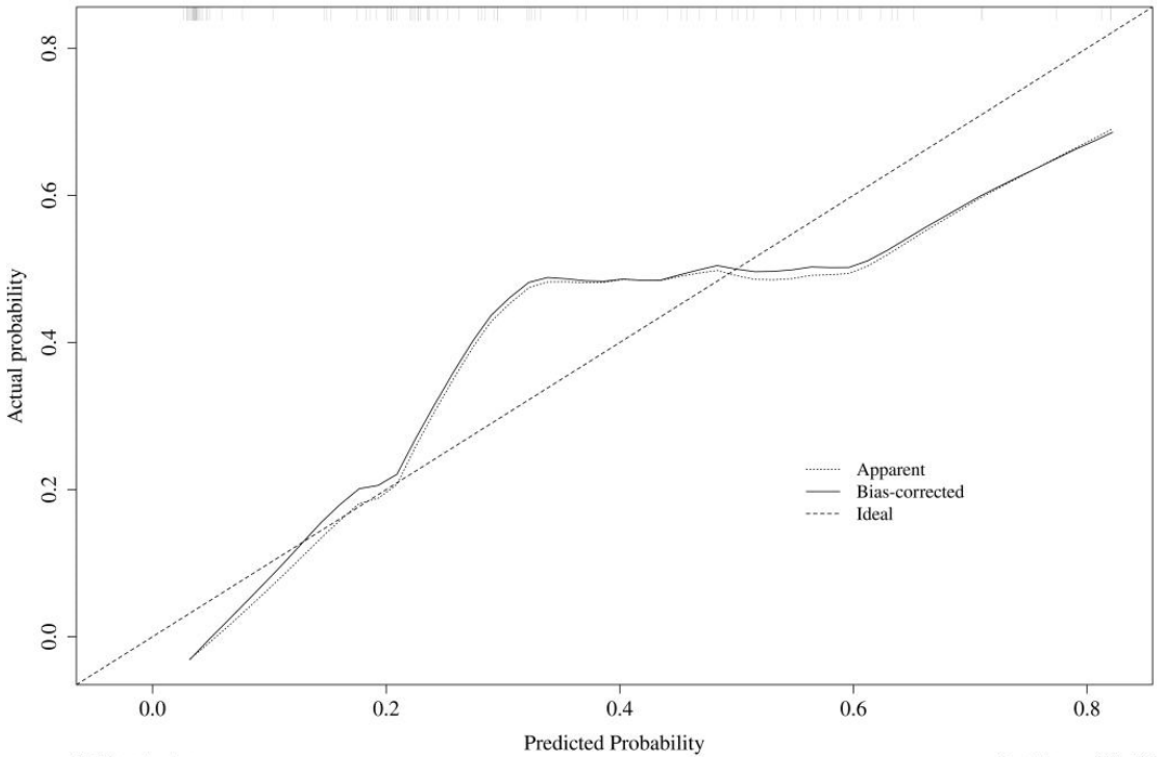

Figure 12. Verification group calibration curve. Note: Apparel: apparent prediction; Bias corrected: prediction after correction; Ideal: ideal reference line.

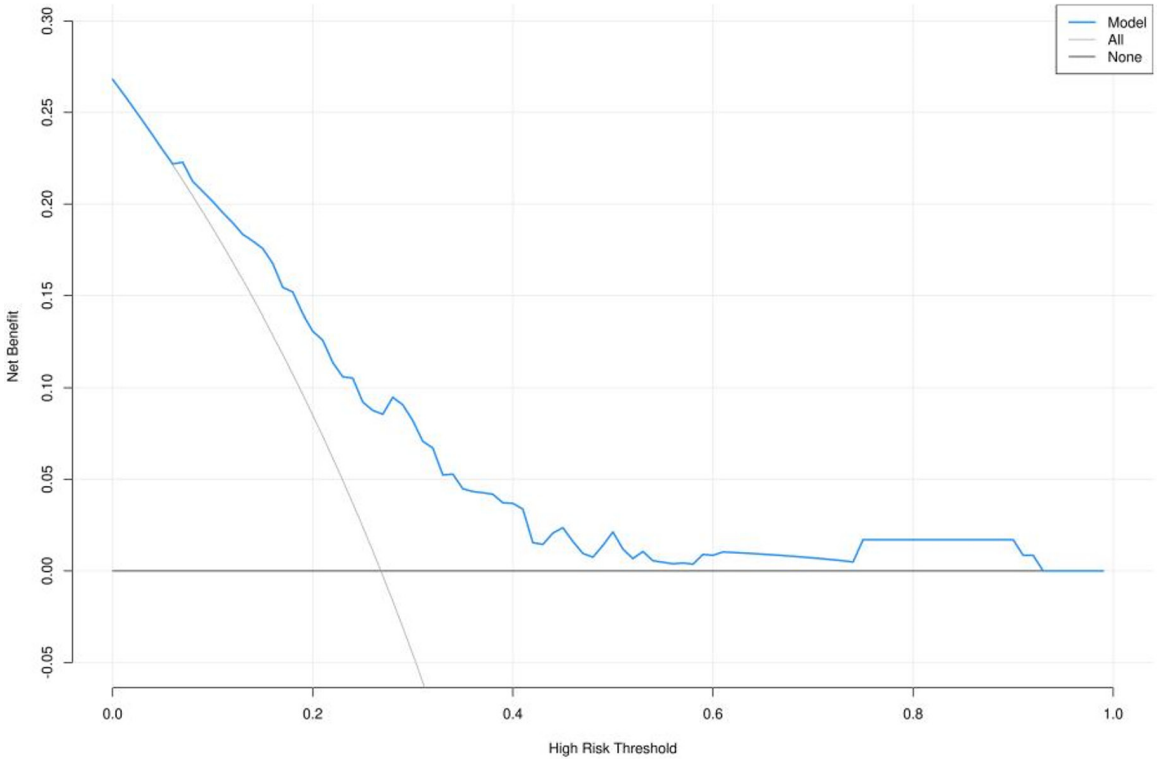

Figure 13. DCA curve of model group. Note: Model: this model; All: complete intervention; None: no intervention. DCA, decision curve analysis.

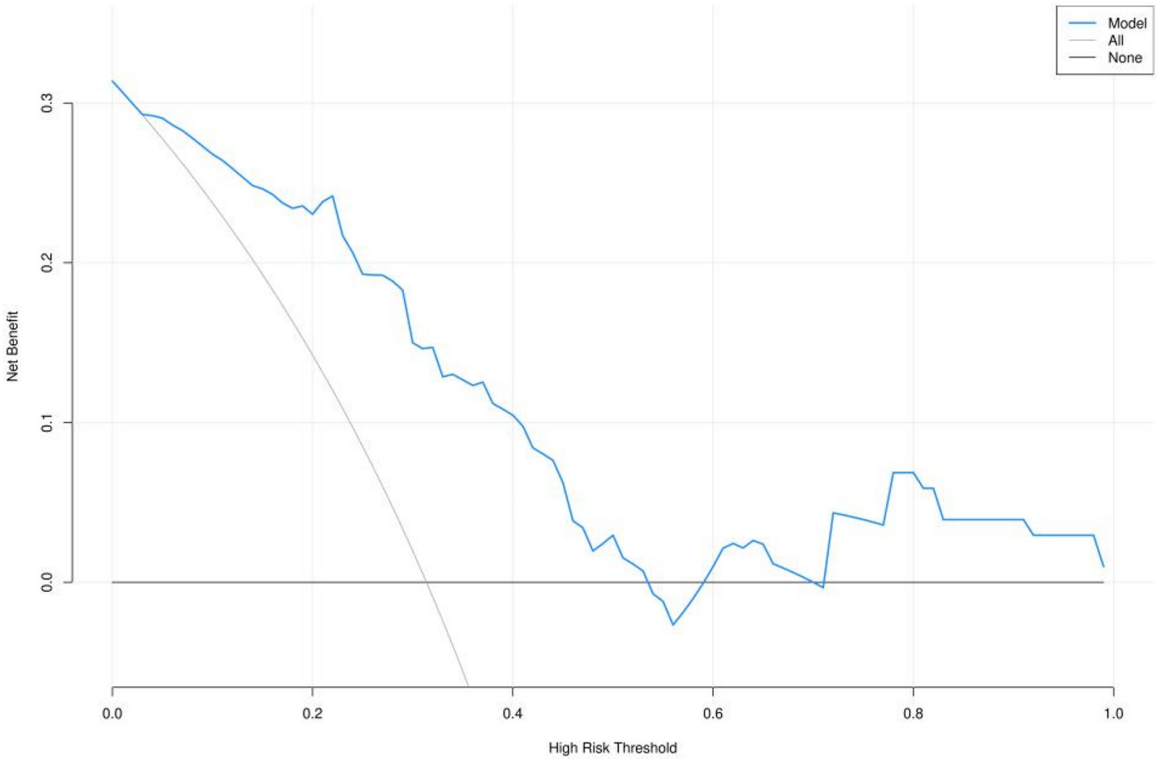

Figure 14. Validation group DCA curve. Note: Model: this model; All: complete intervention; None: no intervention. DCA, decision curve analysis.

strategies are recommended for PAH parturients. For elective cesarean section patients with NYHA I-II grade and mild-to-moderate PAH without spinal anesthesia contraindications, spinal anesthesia with PAH-stratified individualized local anesthetic dosing and targeted fluid management is preferred to ensure hemodynamic stability. For patients with NYHA grade III-IV, severe PAH, or spinal anesthesia contraindications, general anesthesia is recommended with strengthened intraoperative airway management and circulatory regulation to reduce stress fluctuations. For emergency cesarean section, spinal anesthesia should be prioritized if feasible, with immediate conversion to general anesthesia for unstable maternal circulation to maximize maternal and neonatal safety.

This study has several limitations. First, it was a single-center retrospective study with a limited sample size, which may restrict the generalizability of the conclusions. Second, inherent clinical selection bias exists in anesthesia modality selection: severe PAH patients are more likely to receive general anesthesia clinically. Although propensity score matching was used to balance baseline data, residual confounding bias cannot be completely eliminated. Future multi-center, large-sample prospective studies are needed to further verify the study conclusions.

Conclusion

Spinal anesthesia provides safer and more stable perioperative hemodynamic conditions for PAH parturients undergoing cesarean section. The combined evaluation of preoperative clinical indicators can effectively predict postoperative adverse outcomes in this patient population.

Acknowledgements

This study was supported by the 2024 Yingtan City Guiding Science and Technology Plan Project. Grant No: 202423-39821.

Disclosure of conflict of interest

None.

Address correspondence to: Nanyan Xi, Department of Anesthesiology, Yingtan 184 Hospital,

China Rong Tong Medical Healthcare Group Co., Ltd., Yingtan 335000, Jiangxi, China. E-mail: bb12102024@163.com

References

[1] Yang M, Wang J, Zhang X, Zhuang Q, Wang R, Shen J and Lin J. Incidence and long-term outcomes of pregnant women complicated with PAH during different pregnancies: a prospective cohort study from China. Int J Cardiol 2021; 326: 178-183.

[2] Chen G, Zhang Z, Zhao X and Huang K. Maternal and neonatal outcomes in pregnancies complicated with pulmonary hypertension: a retrospective cohort study. Eur J Med Res 2025; 30: 717.

[3] Kamp JC, von Kaisenberg C, Greve S, Winter L, Park DH, Fuge J, Kühn C, Hoeper MM and Olsson KM. Pregnancy in PAH: midterm outcomes of mothers and offspring. J Heart Lung Transplant 2021; 40: 229-233.

[4] Rudienė V, Kaplerienė L, Jančauskaitė D, Meškėnė E, Palevičiūtė E, Laukytė-Slėnienė M, Gasiūnaitė D, Ramašauskaitė D, Jurevičienė E and Gumbienė L. Pregnancy in congenital heart disease, complicated by PAH-A challenging issue for the pregnant woman, the foetus, and healthcare professionals. Medicina (Kaunas) 2022; 58: 476.

[5] Low TT, Guron N, Ducas R, Yamamura K, Charla P, Granton J and Silversides CK.PAH in pregnancy-a systematic review of outcomes in the modern era. Pulm Circ 2021; 11: 20458940211013671.

[6] Ring L, Landau R and Delgado C. The current role of general anesthesia for cesarean delivery. Curr Anesthesiol Rep 2021; 11: 18-27.

[7] Humbert M, Kovacs G, Hoeper MM, Badagliacca R, Berger RMF, Brida M, Carlsen J, Coats AJS, Escribano-Subias P, Ferrari P, Ferreira DS, Ghofrani HA, Giannakoulas G, Kiely DG, Mayer E, Meszaros G, Nagavci B, Olsson KM, Pepke-Zaba J, Quint JK, Rådegran G, Simonneau G, Sitbon O, Tonia T, Toshner M, Vachiery JL, Vonk Noordegraaf A, Delcroix M and Rosenkranz S; ESC/ERS Scientific Document Group. 2022 ESC/ERS Guidelines for the diagnosis and treatment of pulmonary hypertension. Eur Heart J 2022; 43: 3618-3731.

[8] Shi X, Xu C, Wen Y, Jiang M, Yu H, Wang X, Yuan H and Feng S. Perinatal outcome of emergency cesarean section under neuraxial anesthesia versus general anesthesia: a seven-year retrospective analysis. BMC Anesthesiol 2024; 24: 33.

[9] Sankar A, Johnson SR, Beattie WS, Tait G and Wijeysundera DN. Reliability of the American Society of Anesthesiologists physical status scale in clinical practice. Br J Anaesth 2014; 113: 424-432.

[10] Regitz-Zagrosek V, Roos-Hesselink JW, Bauersachs J, Blomström-Lundqvist C, Cífková R, De Bonis M, Iung B, Johnson MR, Kintscher U, Kranke P, Lang IM, Morais J, Pieper PG, Presbitero P, Price S, Rosano GMC, Seeland U, Simoncini T, Swan L and Warnes CA; ESC Scientific Document Group. 2018 ESC guidelines for the management of cardiovascular diseases during pregnancy. Eur heart J 2018; 39: 3165-3241.

[11] Apgar V. The newborn (Apgar) scoring system. Reflections and advice. Pediatr Clin North Am 1966; 13: 645-650.

[12] Ballard W 3rd, Dixon B, McEvoy CA and Verma AK. PAH in pregnancy. Cardiol Clin 2021; 39: 109-118.

[13] Kissin I. Components of general anesthesia: history of the concept transformation. Anesth Analg 2023; 137: 702-707.

[14] Salven D, Sykes D, Erickson M, Than K, Grossi P, Crutcher C and Abd-El-Barr M. Regional anesthesia in spine surgery: a narrative review. J Am Acad Orthop Surg 2023; 40-50.

[15] Wang P, Chen X, Zhang J and Ma Y. Continuous epidural anesthesia with double catheters for cesarean section in a patient with severe pulmonary hypertension: a case report. Medicine (Baltimore) 2021; 100: e27979.

[16] Tamunobelema DMS and Uruaka CI. General anaesthetic agents and their implication on the cardiovascular system: a systematic review. Saudi J Med Pharm Sci 2023; 9: 171-184.

[17] Ranjan AK and Gulati A. Controls of central and peripheral blood pressure and hemorrhagic/hypovolemic shock. J Clin Med 2023; 12: 1108.

[18] Meng ML, Arendt KW, Banayan JM, Bradley EA, Vaught AJ, Hameed AB, Harris J, Bryner B and Mehta LS; American Heart Association Council on Cardiovascular Surgery and Anesthesia; Council on Cardiopulmonary, Critical Care, Perioperative and Resuscitation; and Council on Peripheral Vascular Disease. Anesthetic care of the pregnant patient with cardiovascular disease: a scientific statement from the American Heart Association. Circulation 2023; 147: e657-e673.

[19] Chen N, Wei X, Liu SX and Wang ZY. The effect of different anesthesia methods on hemodynamics and prognosis during cesarean section in women with severe pulmonary hypertension. J Chin Pract Diagn Ther 2023; 37: 1278-1282.

[20] DesJardin JT, Kolaitis NA, Kime N, Kronmal RA, Benza RL, Elwing JM, Lammi MR, McConnell JW, Presberg KW, Sager JS, Shlobin OA and De

Marco T; PHAR Investigators. Age-related differences in hemodynamics and functional status in PAH: baseline results from the Pulmonary Hypertension Association Registry. J Heart Lung Transplant 2020; 39: 945-953.

[21] Langley-Evans SC, Pearce J and Ellis S. Overweight, obesity and excessive weight gain in pregnancy as risk factors for adverse pregnancy outcomes: a narrative review. J Hum Nutr Diet 2022; 35: 250-264.

[22] Zhang Q, Zhu F, Shi G, Hu C, Zhang W, Huang P, Zhu C, Gu H, Yang D, Li Q, Niu Y, Chen H, Ma R, Pan Z, Miao H, Zhang X, Li G, Tang Y, Qiao G, Yan Y, Zhu Z, Zhang H, Han F, Li Y, Lin J and Chen H. Maternal outcomes among pregnant women with congenital heart disease-associated pulmonary hypertension. Circulation 2023; 147: 549-561.

[23] Zhang H, Wang Y, Wu Y, Luo Z, Zhong M, Hong Z and Wang D. Intrathecal anesthesia prevents ventricular arrhythmias in rats with myocardial ischemia/reperfusion. Pharmacology 2024; 109: 253-265.

[24] Wang J and Lu J. Anesthesia for pregnant women with pulmonary hypertension. J Cardiothorac Vasc Anesth 2021; 35: 2201-2211.