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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-089734
Article Type:	Original research
Date Submitted by the Author:	16-Jun-2024

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Keywords:	Maternal medicine < OBSTETRICS, PERINATOLOGY, Postpartum Women < Postpartum Period, PREVENTIVE MEDICINE

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Postpartum Hemorrhage Following Vaginal Delivery: A Comprehensive Analysis and Development of Predictive Models for Etiological Subgroups

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Abstract:

Objective: This study aimed to dissect the etiological subgroups of postpartum hemorrhage (PPH) that occur after vaginal delivery. Our goal was to craft and validate predictive models to guide clinical decision-making and optimize resource allocation..

Methods: Conducted across three hospitals from 2016 to 2022, the study enrolled 29,842 women who underwent vaginal delivery. PPH was categorized into uterine atony (UA), placental factors (PF), cervical trauma (CT), and coagulation abnormalities (CA) by etiology. Logistic regression identified risk factors for each PPH subgroup and constructed predictive models. The cohort was segmented into a training dataset (70%) and an internal validation dataset (30%), complemented by an additional cohort for external validation. Model performance was rigorously assessed using R software, with a focus on discrimination, calibration, and clinical utility as benchmarked by Decision Curve Analysis (DCA).

Results: The logistic regression for overall PPH and UA-PPH showcased high discrimination (AUCs of 0.807 and 0.794, respectively), coupled with commendable calibration and DCA-assessed clinical utility, culminating in the development of a nomogram for risk prediction. The PF-PPH model exhibited a modest AUC of 0.739, while the CT-PPH and CA-PPH models demonstrated suboptimal clinical utility and calibration.

Conclusion: The study identified factors associated with PPH and developed models with good performance for overall PPH and UA-PPH. The nomogram offers a valuable tool for risk prediction. However, models for PF-PPH, CT-PPH, and CA-PPH require further refinement. Future research should focus on larger samples and multi-center validation for enhanced model generalizability.

Keywords: Postpartum Hemorrhage, Vaginal Delivery, Etiological Subgroups, Predictive Models, nomogram

Background

Postpartum hemorrhage (PPH) is a widespread and serious medical condition that poses significant risks to women's health around the world. It is particularly devastating in developing countries, where it is a principal contributor to maternal mortality. [1] It is estimated that approximately 1.4 million maternal deaths globally are tied to PPH each year, with the tragic loss of a woman's life to this condition occurring every four minutes.[2, 3]. In Australia, the incidence of PPH increased from 6.3% in 2000 to 8.0% in 2009. [4] Similarly, in the United States, the rate of PPH rose from 2.7% in 1999 to 3.2% in 2014. [5] In China, despite a relatively lower maternal mortality rate of 17.8 per 100,000 in 2019, PPH accounted for one-quarter of these deaths.[6]

The World Health Organization (WHO) has conducted an analysis revealing that while PPH is a significant factor in maternal mortality and morbidity, the mortality rates vary considerably across different regions.[7] In high-income countries, the risk of death due to PPH is significantly lower than in low-income countries.[8] In high-income nations, the substantial blood loss primarily caused by PPH accounts for 13.4% of overall maternal mortality, while in Africa and Asia, this figure stands at 34% and 30.8%, respectively. [7] The international obstetric community is actively engaged in research to better understand the incidence, risk factors, and management strategies for PPH.[9-11]. Despite the establishment of global clinical guidelines and the identification of various risk factors, further exploration is needed to enhance our understanding and management of PPH.[12, 13].

PPH can be etiologically classified into uterine atony (UA), placental factors (PF), cervical trauma (CT), and coagulation abnormalities (CA), each requiring distinct clinical management and treatment strategies. [14] Clear etiological classification is crucial for developing preventive strategies, formulating management plans, and rational allocation of medical resources.[15] While numerous cohort studies have focused on identifying risk factors for PPH, there is a scarcity of studies that quantify and weigh these risk factors for a comprehensive PPH risk assessment.[16-18] Given the complexity of PPH and the interplay of multiple risk factors, a holistic approach is necessary to accurately assess the risk of PPH.

Clinical prediction models (CPMs) have been widely applied in clinical settings in recent years. By constructing CPMs, physicians and patients can make better medical decisions, and health departments at all levels can allocate medical resources more rationally. These models play an irreplaceable role in primary prevention (assessing the quantitative risk of future diseases) and secondary prevention (constructing highly sensitive and specific diagnostic schemes, practicing "early detection, early diagnosis, early treatment"), reflecting significant health economic value.

There is a gap in research regarding the development of clinical prediction models for women specifically following vaginal delivery. Many studies are constrained by limited sample sizes, which can affect the robustness of the models[19]. Other research has focused on PPH prediction models for women undergoing cesarean sections.[20] Our study aims to address this gap by constructing a clinical prediction model tailored to PPH after vaginal delivery. By analyzing clinical data and risk factors through logistic regression, we can determine the relative impact of each factor on the likelihood of PPH. We further refine our model by performing secondary fitting based on the four etiological subgroups, creating a nomogram that enhances the precision of predicting high-risk populations for PPH. This work provides essential insights for the prevention and management of this critical condition.

Materials and methods

Data Sources and Ethics Statement

This cohort study was conducted at the obstetric wards of Shengjing Hospital of China Medical University, Liaoning Maternal and Child Health Hospital, and Shenyang Women's and Children's Hospital. The study population comprised women who underwent vaginal delivery between January 1, 2016, and December 31, 2022. The outcomes of interest were fetal birth outcomes within the first 24 hours postpartum. Inclusion criteria were women who consented to participate after being informed of the study's scope. Exclusion criteria were defined as follows: age under 18 or over 50 years, delivery occurring at less than 37 weeks or more than 42 weeks of gestation, multiple births, and instances of induced labor, stillbirth, or fetal death. Comprehensive data encompassing maternal characteristics, obstetric and gynecologic history, pregnancy complications, and details of the delivery process and neonatal conditions were collected (Supplement 1). To protect participant privacy, all data were anonymized. The study protocol was approved by the Ethical Review Committee of Shengjing Hospital of China Medical University (No. 2016PS344K), and written information about the study was provided to all participants.

Sample Size Calculation

The study was designed as an observational analysis to estimate the incidence of PPH at less than 10% and statistical parameters set at a significance level (α) of 0.05 and a power (1-β) of 0.95, the required sample size was determined to be 384 patients to achieve an absolute precision of 5%.

Covariates

A range of covariates were taken into account, including:(1) Age, categorized as <25, 25-29, 30-34, and ≥35 years; (2) Ethnicity, divided into Han, Manchu, and other; (3) Education level, classified as high school or below, bachelor's degree, and postgraduate or above; (4) Occupation, categorized as unemployed, light physical labor, moderate physical labor, and heavy physical labor (based on the International Physical Activity Questionnaire, IPAQ); (5) Monthly household income per capita, divided into <0.5, 0.5-2.0, 2.0-5.0, and >5.0 thousand yuan; (6) Pre-pregnancy BMI, categorized as underweight (<18.5 kg/m^2), normal (18.5-23.9 kg/m^2), overweight (24-27.9 kg/m^2), and obese (≥28 kg/m^2); (7) Gravidity, categorized as 1, 2, or ≥3 times; (8) Parity, divided into 0, 1, or ≥2 times; (9) Gestational age, categorized as <38, 38-40, and >40 weeks; (10) Delivery time, divided into daytime (8-16), evening (17-23), and night (0-7) shifts; (11) Total duration of labor, categorized as normal (≤24 hours) and prolonged (>24 hours); (12) Latent phase of the first stage, categorized as normal (primiparous ≤20 hours, multiparous ≤14 hours) and prolonged (primiparous >20 hours, multiparous >14 hours); (13) Active phase of the first stage, categorized as normal (≤8 hours) and prolonged (>8 hours); (14) Second stage duration, categorized as normal and prolonged based on specific criteria for primiparous and multiparous women with or without analgesia; (15) Third stage duration, categorized as normal (≤30 minutes) and prolonged (>30 minutes).

Etiology Subgroup

Patients were categorized into groups with or without postpartum hemorrhage based on the presence of postpartum bleeding and its underlying etiology, which included UA, PF, CT, and CA.

Model Construction

For the purpose of our investigation, we have categorized the participants from the Shengjing hospital of China Medical University as Cohort I. This cohort was systematically split into a training dataset and an internal validation dataset with a ratio of 7:3. The training dataset was instrumental in developing the predictive model, while the internal validation dataset served to assess the model's predictive accuracy. An additional cohort, comprising participants from two other hospitals, was designated as Cohort II. This external dataset was used to validate the model's general applicability and its efficacy in real-world clinical scenarios.

Within the confines of the datasets, we employed both univariate and multivariate logistic regression analyses to identify potential risk factors across various subgroups. These factors were then subjected to a rigorous selection process for inclusion in the predictive model. The selected factors were further analyzed using multivariate logistic regression in training dataset to discern their discriminative power, thereby establishing them as predictive indicators for the model. The model's features were meticulously optimized through logistic regression, and the performance of these models was corroborated using both the test and validation datasets to ascertain the most accurate predictive model.

Evaluating the Performance of the Models

The area under the receiver operating characteristic curve (AUC) was the primary metric used to evaluate the discrimination of our models. An AUC value above 0.75 suggests excellent model discrimination, while an AUC below 0.6 indicates poor discrimination. Calibration curves were used to assess the models' accuracy, with closer alignment between observed and predicted incidence rates indicating higher model fidelity. Decision Curve Analysis (DCA) was also employed to evaluate the clinical utility of the models, offering a thorough assessment of the models' net benefits across various clinical scenarios.

Nomogram Development

Nomograms for postpartum hemorrhage and its four etiological subgroups were crafted to offer a visual representation of the risk scores derived from the logistic regression analysis. This tool simplifies the interpretation of complex statistical outcomes, providing a more straightforward approach to understanding risk assessments.

Statistical Analysis

All statistical computations, construction of traditional logistic models, and calculations of model discrimination and calibration were carried out using R version 3.6.3 from the R Foundation for Statistical Computing, Vienna, Austria. This software facilitated the development of traditional logistic predictive models and their subsequent evaluation for discriminative power, calibration, and clinical utility. Continuous variables conforming to the normal distribution were expressed as the mean ± standard deviation (SD), while non-normally distributed continuous variables were presented as medians with interquartile ranges. Categorical data were analyzed using chi-square tests, and continuous variables were analyzed using ANOVA or Mann-Whitney tests, as appropriate. Variables were adjusted as dummy variables, and odds ratios (OR) with corresponding 95% confidence intervals (95% CI) were calculated using univariate and multivariate logistic regression analyses, with significance levels set at $P < 0.05$ or $P < 0.001$.

Results

From 2016 to 2022, a total of 27,389 patients underwent vaginal delivery at the Shengjing Hospital of China Medical University. Forty-two patients under 18 years of age or over 50 years old were excluded. Additionally, 2,456 patients with gestational age less than 37 weeks or more than 42 weeks at delivery, 6 patients with multiple births, and 52 patients with induced labor, stillbirth, or fetal death were also excluded. Ultimately, 24,833 patients met the inclusion criteria and were enrolled in the cohort. According to the inclusion and exclusion criteria, a total of 5,099 patients in cohort II were included in the external validation dataset. The general characteristics of all patients are presented in Table 1. All patients were followed up within 24 hours after delivery for neonatal outcomes, with a follow-up rate of 100%. The patient selection criteria flowchart is shown in Figure 1.

Comparison of Basic Characteristics and Risk Analysis for Postpartum Hemorrhage (PPH) and Its Subgroups

Based on the occurrence of postpartum hemorrhage, the parturients in cohort one were divided into two groups: the non-PPH group and the PPH group. Similarly, within the etiological subgroups, they were categorized into UA-PPH and non-UA-PPH groups, PF-PPH and non-PF-PPH groups, CT-PPH and non-CT-PPH groups, and CA-PPH and non-CA-PPH groups. The comparison of basic characteristics and analysis of risk factors for each group are presented in Supplementary Tables 1-5.

In the multivariate analysis of risk factors, apart from age, parity, pre-pregnancy BMI, anemia, premature rupture of membranes, and combined placenta retention/placenta accreta/placental implantation, other specific risk factors were found to be associated with specific etiologies of postpartum hemorrhage. For instance, polyhydramnios was associated with UA-PPH; analgesia during labor, instrumental assistance, and cervical/vaginal/perineal lacerations were associated with the occurrence of CT-PPH (Table 2).

Selection of Predictive Factors for PPH and Its Subgroups in the Training Dataset

Through random sampling of cohort one, 70% of the data (N=17,383) from parturients were used to form the training dataset, with the remaining approximately 30% (N=7,450) forming the internal validation dataset. Multivariate analysis of risk factors for PPH and its subgroups was performed again in the training dataset, with results presented in Supplemental Table 1. After selection, predictive models were constructed for each group using the selected risk factors.

Evaluation of Predictive Model Discrimination

The ROC curves were plotted using R software for the PPH group and its various subgroups across the training dataset, internal and external validation dataset.

The results indicated that the predictive models, namely PH-Logistic, UA-PPH-Logistic, PF-PPH-Logistic, CT-PPH-Logistic, and CA-PPH-Logistic, demonstrated high discriminative power in the training dataset with AUCs of 0.807 (95% CI: 0.792-0.821), 0.794 (95% CI: 0.777-0.811), 0.796 (95% CI: 0.761-0.830), 0.935 (95% CI: 0.901-0.969), and 0.807 (95% CI: 0.792-0.821), respectively.(Figure 2A-E) However, the PF-PPH-Logistic model exhibited only moderate discrimination with an AUC of 0.739 (95% CI: 0.666-0.813) in the internal validation dataset. Furthermore, the CA-PPH-Logistic model showed significantly lower discrimination in the external validation dataset with an AUC of 0.662 (95% CI: 0.450-0.873), which was notably inferior to its performance in the training and test datasets . This discrepancy may be attributed to the lower proportion of patients with coagulation disorders causing PPH in the validation dataset.

Assessment of Predictive Model Calibration

Calibration curves for the PPH and its subgroups were plotted for the Logistic predictive model within the training dataset (Supplemental Figure 1A-E). The performance of the PF-PPH-Logistic, particularly the CT-PPH-Logistic, and CA-PPH-Logistic models was suboptimal in certain aspects, with lower calibration, as observed in the test and external validation datasets (Supplemental Figure 1 F-J, Supplemental Figure 1K-O).

Evaluation of Clinical Utility of Predictive Models

In the evaluation of clinical utility, the PPH-Logistic and UA-PPH-Logistic models demonstrated satisfactory performance across all datasets. However, the clinical utility of the PF-PPH-Logistic, CT-PPH-Logistic, and CA-PPH-Logistic models was found to be relatively poor. (Supplemental Figure 2A-O)

Nomogram Construction

Using R software, we constructed nomograms for PPH and its four subgroups, with the results presented in Figure 3A-E. Physicians can assess the risk probability of PPH occurrence by summing the individual scores on the nomogram. This practical tool aids in a more precise estimation of PPH risk, thereby enhancing clinical decision-making.

Discussion

Maternal mortality has emerged as a pivotal indicator in global maternal and child health, serving as a significant benchmark for assessing the socioeconomic status of nations. Consequently, the effective reduction, prevention, and improvement of conditions leading to maternal deaths have become a focal point for public health initiatives worldwide. Among the various causes of maternal mortality, PPH stands out as a preventable condition that has attracted considerable attention. [17, 18] With the rise in global economic standards and the evolution of medical technologies, there has been an approximate 50% decrease in the worldwide maternal mortality rate between 1990 and 2015. In China, the maternal mortality rate has seen a dramatic reduction of 98.78%[21] since the establishment of the People's Republic of China. Despite these advancements, a substantial proportion of maternal deaths, estimated between 27% and 40%[22], remain avoidable due to a range of factors, including inadequate social and medical interventions. PPH is a critical area of focus within this context, and the prediction and prevention of PPH to reduce avoidable maternal mortality present a significant challenge on the global stage.

The advent of the big data era has brought new opportunities for the management of PPH. The era is characterized by the digitization and standardization of medical records, along with an increasing volume of data, which has ushered in an era of data-driven management and treatment for maternal care. Leveraging big data analytics for disease risk prediction can contribute to the reduction of avoidable maternal deaths.

A review of the literature reveals over 200 prognostic models in obstetrics, three of which are pertinent to PPH.[23] However, few models have been applied in routine clinical practice, and the majority of studies have not provided model formulas, hindering independent external validation. The earliest PPH prediction model, dating back to 1994, originated from a case-control study in Zimbabwe[24], where PPH was defined as blood loss exceeding 600 milliliters following an unassisted vaginal delivery. This study included 150 PPH patients and 299 patients with normal deliveries, with a low positive predictive value of less than 7% and only 35.0% of patients experiencing postpartum bleeding. Since then, approximately ten additional PPH prediction models have been published. These models have varied in focus, with some concentrating on the relationship between placenta previa and PPH, while others have included only vaginal deliveries[24-27] or cesarean sections[20, 28, 29], and some have targeted women with placental implantation disorders[30] or general obstetric populations[31]. PPH research has been conducted in hospitals across various countries, including Italy, China, France, the United States, the United Kingdom, South Korea, the Netherlands, Spain, Zimbabwe, Denmark, and Egypt. From the 14 published studies, a total of 124 independent variables were identified as potential predictors (ranging from 5 to 38 per study), and 64 variables were ultimately selected for the final models (an average of 5-15 factors per study). Common predictors included parity, low pre-pregnancy hemoglobin, antenatal bleeding, maternal age over 35, gestational age, high neonatal weight, multiple pregnancies, body mass index (BMI) over 25, previous cesarean section, anterior placenta, and retained placenta. These predictors have also been incorporated into our predictive model.

Once a clinical prediction model is developed, it must undergo validation and evaluation to assess the model's effectiveness, reproducibility, and portability. Published PPH prediction models have reported AUCs ranging from 0.70[25] to 0.90[27], with external validation AUCs of 0.83[20], which are comparable to the results of our study. In addition to discrimination, calibration is essential to evaluate the consistency between the predicted probabilities of clinical outcomes and the observed event probabilities. Only a few studies, such as one by Albright in 2019 on the prediction of PPH following cesarean section, have utilized calibration curves[32], while most have employed the Hosmer-Lemeshow goodness-of-fit test to compare predicted probabilities with actual event probabilities for significant differences. The Hosmer-Lemeshow test, however, has limited efficacy in small-sample prediction models as it does not quantify model calibration[33, 34]or provide direction or magnitude of mis calibration[35].

The Decision Curve Analysis (DCA)[35] has been used to evaluate the clinical utility of models, focusing on the selection of true positives from positive patients to avoid unnecessary medical resource consumption and reduce harm from overtreatment of false positives. DCA is particularly suited for scenarios where symptoms suggest the possibility of disease but a diagnosis has not yet been confirmed, guiding the decision on whether or what kind of screening method to adopt for disease diagnosis. The DCA's axes represent the threshold probability (P) and net benefit (NB), allowing for the determination of intervention measures based on the predicted probability of adverse events.[36]

In essence, both ROC and DCA can be used to assess the quality of predictive models, but they differ fundamentally in their theoretical constructs. While ROC combines sensitivity and specificity to compare the accuracy of predictive models through the AUC, the highest AUC does not necessarily represent the optimal model in clinical practice. For instance, in this study, patients in the CA-PPH group, due to coagulation disorders, all underwent cesarean section deliveries to minimize the number of false positives. This requires decision-makers to consider practical issues, as a high ROC does not always indicate the best treatment approach. Furthermore, for some extreme cases, the accuracy of ROC becomes less critical, and DCA evaluation results are needed for reference.

Statistical analysis of previously published PPH data has shown that factors such as general anesthesia in pregnant women, prolonged use of oxytocin, excessive uterine tension (multiple pregnancies, polyhydramnios), and chorioamnionitis are all associated with uterine atony, potentially increasing the risk of postpartum bleeding. Previous studies have suggested that for pregnant women with high-risk factors, assessing and selecting appropriate treatment options and management based on the type and weight of different risks can reduce the risk of adverse pregnancy outcomes or death[37]. Early prediction and intervention are key measures in reducing maternal mortality, with studies finding that timely interventions can effectively lower maternal mortality rates by 10%[38]. Establishing a model that predicts the risk of PPH following vaginal delivery and guides clinical practice is a significant task for maternal and child health.

Limitation

Although some subtypes in this study have shown promising predictive results, the clinical application of the logistic regression clinical prediction models for PF-PPH, CT-PPH, and CA-PPH groups is limited due to the insufficient positive sample size in the subgroups, not fully achieving the initial goal of etiology-based PPH prediction. Compared to previously published prediction models, this study's test set is a single-center study specifically for vaginal delivery PPH, with a limited number of positive samples; the existing external validation datasets are also from hospitals of the same region and level, lacking in diversification and generalizability. Therefore, in addition to future plans for multi-center collaboration and increased sample sizes, we aim to seek higher-quality prediction methods to provide more convincing evidence for clinical prediction.

Conclusion

In conclusion, our study has successfully developed and validated predictive models for PPH following vaginal delivery, offering a novel approach to risk assessment in this critical area of maternal health. The models, particularly for UA-PPH and CT-PPH, demonstrated high discriminative power and clinical utility, with the nomogram providing a user-friendly tool for clinicians. Despite the promising results, limitations exist in the application of the PF-PPH, CT-PPH, and CA-PPH models due to the insufficient positive sample size in these subgroups. The generalizability of our findings may also be limited by the single-center nature of the study and the regional characteristics of the included hospitals. Future research should aim to expand the sample size and include multi-center data to improve the models' applicability and robustness. This study contributes to the growing body of evidence on PPH management and has the potential to influence policy and practice, ultimately enhancing maternal care and outcomes.

Figure legend

Figure 1. Patient Selection Criteria Flowchart.

Figure 2. AUC Curve for Postpartum Hemorrhage (PPH) Group and four subgroups. A. PPH Group; B. Uterine Atony PPH Group; C. Placental Factors PPH Group; D. Cervical Trauma PPH Group; E. Coagulation Abnormalities PPH Group. The blue line signifies the training dataset, which is employed to evaluate the model's predictive capabilities following the training phases. The green line corresponds to the internal validation dataset, pivotal for refining model parameters and for conducting initial assessments of the model's accuracy. The purple line denotes the external validation dataset, which is utilized to ascertain the model's generalizability and to verify its performance in an independent dataset.

Figure 3. Nomograms for Postpartum Hemorrhage (PPH) and Uterine Atony PPH Group. A. PPH Group; B. Uterine Atony PPH Group.

Supplemental Figure 1. Calibration curves for Postpartum Hemorrhage (PPH) Group and four subgroups. A\F\K. PPH Group; B\G\L. Uterine Atony PPH Group; C\H\M. Placental Factors PPH Group; D\I\N. Cervical Trauma PPH Group; E\J\O. Coagulation Abnormalities PPH Group. The blue line signifies the training dataset; The green line signifies the internal validation dataset; The purple line signifies the external validation dataset.

Supplemental Figure 2. Decision Curve Analysis for Postpartum Hemorrhage (PPH) Group and four subgroups. A. PPH Group; B. Uterine Atony PPH Group; C. Placental Factors PPH Group; D. Cervical Trauma PPH Group; E. Coagulation Abnormalities PPH Group. The blue line signifies the training dataset; The green line signifies the internal validation dataset; The purple line signifies the external validation dataset.

List of abbreviations

RP: Refined Peyton;

TTM: Traditional Teaching-mode

DOPS: direct observation of procedural skills

OB-GYN: Obstetrics and Gynecology

CBVI: computer-based video instruction

PEARLS: Promoting Excellence and Reflective Learning in Simulation

OSCE: objective structured clinical assessment

Declarations

Ethics approval and consent to participate

Ethics approval and consent to participate: The study was approved by the Ethics Committee of Shengjing Hospital of China Medical University (No. 2016PS344K, Date.17/12/2016). All participants provided informed consent.

Consent for publication

Not Applicable

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Competing interests

No potential conflict of interest was reported by the author(s).

Funding

This study was supported in part by grants from 345 Talent Project of Shengjing Hospital of China Medical University (No. M0946), and Medical Education Research Project of Liaoning Province (No. 2022-N005-03).

Authors' contributions

JL, DZ and KZ designed the study and drafted the manuscript. HL, MS, and XW done the data collection. YZ and XC designed the statistical analysis plan. DZ has participated the training and reviewed and co-authored the manuscript with ZS.

Acknowledgements

We would like to express our gratitude to all those who helped us during the writing of this manuscript. Thanks to all the peer reviewers for their opinions and suggestions. We would like to acknowledge that Jinke Li and Dandan Zhang have contributed equally to this work.

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Table 1 The general view of the maternal.

Characteristics	Cohort population （N=24,833）	Validation population (N=5009)	P
Age (years) *，N（%）			0.393
<25	1,309 （5.27%）	266 (5.31%)	
25-29	11,736 （47.26%）	2340 (46.71%)	
30-34	9,445 （38.03%）	1959 (39.11%)	
⩾35	2,343 （9.44%）	444 (8.86%)	
Ethnicity，N（%）			0.983
Han	22,222 （89.49%）	4,475 (89%)	
Manchu	1,872 （7.54%）	389 (7.8%)	
Other ethnic groups	739 （2.98%）	145 (2.9%)	
Educational Attainment，N（%）			0.115
High school or below	8,635 （34.77%）	1,742 (35%)	
Bachelor's degree	13,639 （54.92%）	2,703 (54%)	
Postgraduate or higher	2,559 （10.30%）	564 (11%)	
Occupation，N（%）			0.777
Unemployed	11,373 （45.80%）	2,266 (45%)	
Light physical labor	2,825 （11.38%）	569 (11%)	
Moderate physical labor	10,011 （40.31%）	2,038 (41%)	
Heavy physical labor	624 （2.51%）	136 (2.7%)	
Family Per Capita Monthly Income (10,000 yuan)，N（%）			0.9862
<0.5	10,325 （41.58%）	2,080 (42%)	
0.5-2.0	9,534 （38.39%）	1,922 (38%)	
2.0-5.0	3,584 （14.43%）	720 (14%)	
>5.0	1,390 （5.60%）	287 (5.7%)	
Pre-pregnancy BMI （Kg/m2） *，N（%）			<0.001
<18.5（Underweight）	7,294 （29.37%）	1475 (29.45%)	
18.5-23.9（Normal）	15,005 （60.42%）	2963 (59.16%)	
24.0-27.9（Overweight）	1,700 （6.85%）	307 (6.13%)	
>28.0（Obesity）	834 （3.36%）	264 (5.29%)	
Pregnancy History，N（%）			0.565
1	14,985 （60.34%）	3,005 (60%)	
2	6,513 （26.23%）	1,303 (26%)	
⩾3	3,335 （13.43%）	701 (14%)	
Parity (number of deliveries)，N（%）			0.775
0	20,550 （82.75%）	4,127 (82%)	
1	4,152 （16.72%）	853 (17%)	
⩾2	131 （0.53%）	29 (0.6%)	
Gestational Age at Delivery (weeks)，N（%）			0.434

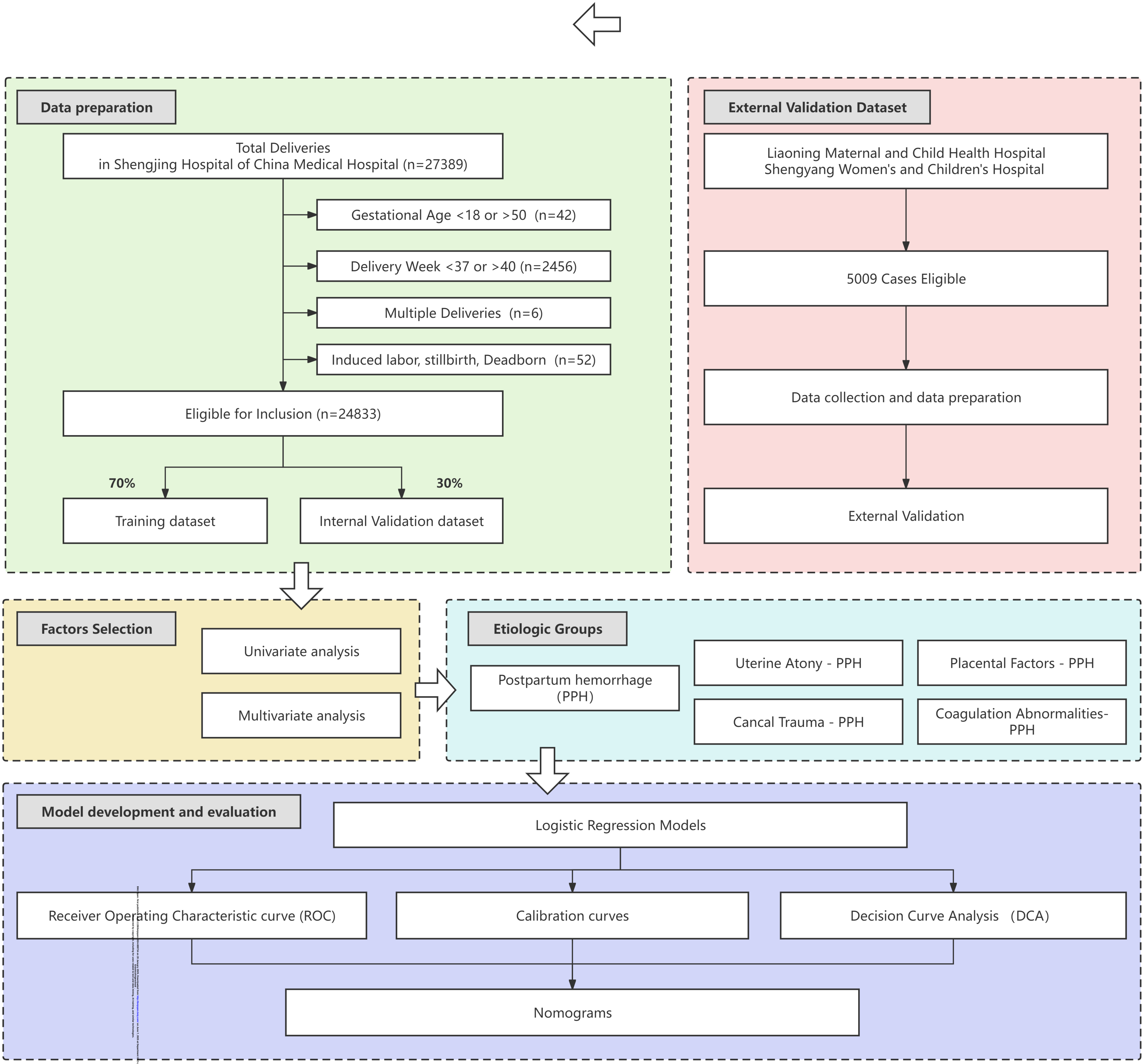
<38	1,507 （6.07%）	296 （5.91%）	
38-40	13,023 （52.44%）	2589 （51.59%）	
>40	10,303 （41.49%）	2129 （42.50%）	
Blood Loss（ml）	393.54±92.53	413.48±124.65	0.081
Postpartum Hemorrhage，N（%）	1,623 （6.54%）	286 （5.71%）	0.032
Due to uterine atony，N（%）	1,225 （4.93%）	266 （5.31%）	0.279
Due to placental factors，N（%）	242 （0.97%）	43 （0.86%）	0.489
Due to Cancal Trauma，N（%）	139 （0.56%）	31 （0.62%）	0.686
Due to coagulation disorders，N（%）	76 （0.31%）	17 （0.34%）	0.705

Table 2: Multivariate Risk Factor Analysis for Postpartum Hemorrhage (PPH) within Subgroups

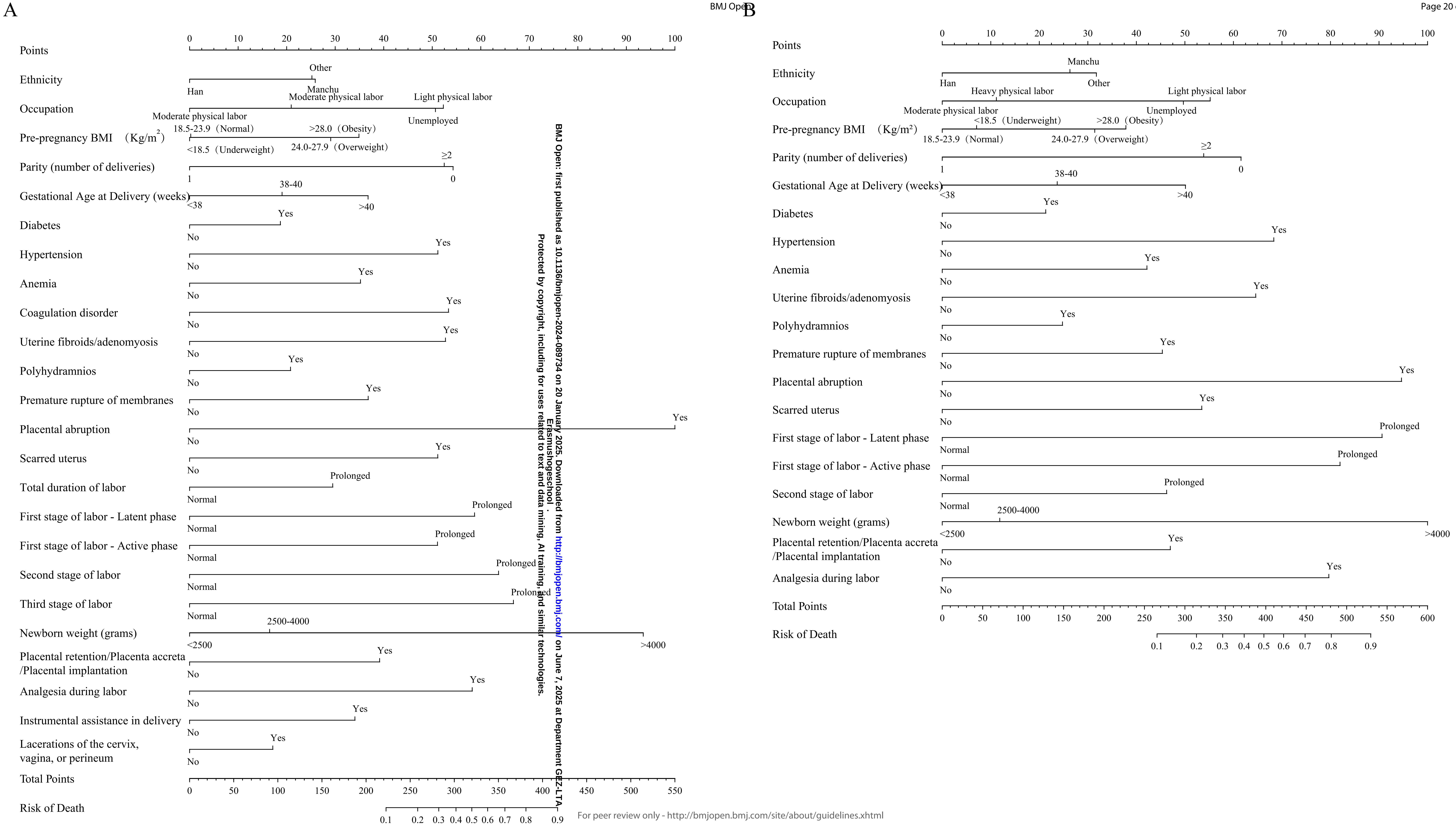
Characteristics	PPH	UA-PPH	PF-PPH	CT-PPH	CA-PPH
		General view			
Age (years)	*	*	-	-	-
Ethnicity	**	**	**	*	-
Educational Attainment	-	-	-	-	-
Occupation	**	**	**	-	*
Family Per Capita Monthly Income (10,000 yuan)	-	-	-	-	-
Pre-pregnancy BMI （Kg/m2）	**	**	**	**	*
Smoking	-	-	-	-	*
Alcohol Consumption	-	-	-	-	-
		Obstetric and Gynecologic History			
Pregnancy History	-	-	-	-	-
Parity (number of deliveries)	**	**	**	*	*
History of miscarriage	-	-	-	-	-
Spontaneous abortion	-	-	-	-	-
Induced abortion or medication abortion	-	-	-	-	-
Induced labor	-	-	-	-	-
Assisted reproductive technology	-	-	-	-	-
Gestational Age at Delivery (weeks)	**	**	*	-	-
Diabetes	**	**	**	*	-
Hypertension	**	**	**	*	-
Anemia	**	**	**	**	*

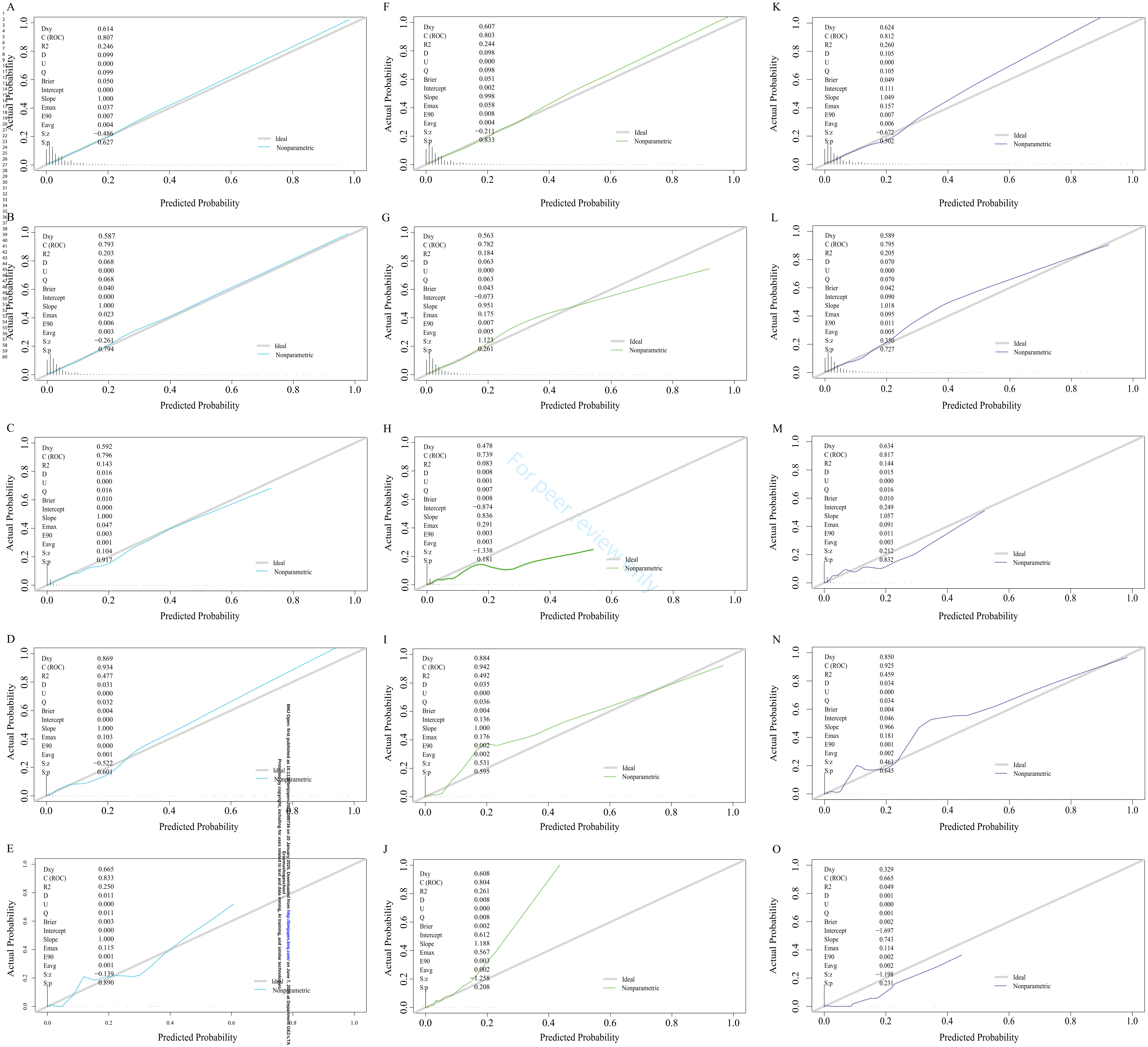
Coagulation disorder	**	-	-	-	*
Uterine fibroids/adenomyosis	**	**	**	*	-
Polyhydramnios	**	**	*	-	-
Umbilical cord entanglement	-	-	-	-	-
Premature rupture of membranes	**	**	**	*	**
Placental abruption	**	**	-	-	-
Vaginal bleeding during pregnancy	-	-	-	-	-
Scarred uterus	**	**	-	-	*
		Delivery Process and Neonatal Conditions			
Time of delivery	-	-	-	-	-
Total duration of labor	**	*	*	*	**
First stage of labor - Latent phase	**	**	-	-	-
First stage of labor - Active phase	**	**	-	-	-
Second stage of labor	**	**	*	**	-
Third stage of labor	**	-	**	*	-
Placental retention/Placenta accreta/Placental implantation	**	**	**	**	**
Analgesia during labor	**	**	-	*	**
Instrumental assistance in delivery	**	-	-	**	-
Lacerations of the cervix, vagina, or perineum	**	-	-		-
Newborn weight (grams)	**	**	-	-	-
Newborn length (centimeters)	-	-	-	-	-

*: P<0.05; **: P<0.001


Data preparation
Total Deliveries
in Shengjing Hospital of China Medical Hospital (n=27389)
Gestational Age <18 or >50 (n=42)
Delivery Week <37 or >40 (n=2456)
Multiple Deliveries (n=6)
Induced labor, stillbirth, Deadborn (n=52)
Eligible for Inclusion (n=24833)
70%
30%
Training dataset
Internal Validation dataset
External Validation Dataset
Liaoning Maternal and Child Health Hospital
Shengyang Women's and Children's Hospital
5009 Cases Eligible
Data collection and data preparation
External Validation
Factors Selection
Univariate analysis
Multivariate analysis
Etiologic Groups
Postpartum hemorrhage (PPH)
Uterine Atony - PPH
Placental Factors - PPH
Cancal Trauma - PPH
Coagulation Abnormalities-PPH
Model development and evaluation
Logistic Regression Models
Receiver Operating Characteristic curve (ROC)
Calibration curves
Decision Curve Analysis (DCA)
Nomograms


A
Sensitivity
Specificity
AUC: 0.807 (0.792–0.821)
AUC: 0.803 (0.781–0.825)
AUC: 0.812 (0.786–0.838)
B
Sensitivity
Specificity
AUC: 0.794 (0.777–0.811)
AUC: 0.782 (0.756–0.807)
AUC: 0.795 (0.764–0.825)
C
Sensitivity
Specificity
AUC: 0.796 (0.761–0.830)
AUC: 0.739 (0.666–0.813)
AUC: 0.816 (0.750–0.882)
D
Sensitivity
Specificity
AUC: 0.935 (0.901–0.969)
AUC: 0.943 (0.903–0.982)
AUC: 0.926 (0.869–0.982)
E
Sensitivity
Specificity
AUC: 0.831 (0.769–0.892)
AUC: 0.802 (0.655–0.950)
AUC: 0.662 (0.450–0.873)


A
Points
Ethnicity
Han
Other
Manchu
Occupation
Moderate physical labor
Light physical labor
Unemployed
Pre-pregnancy BMI (Kg/m2)
18.5-23.9 (Normal)
>28.0 (Obesity)
<18.5 (Underweight)
24.0-27.9 (Overweight)
Parity (number of deliveries)
≥2
Gestational Age at Delivery (weeks)
38-40
<38
>40
Diabetes
Hypertension
Anemia
Coagulation disorder
Uterine fibroids/adenomyosis
Polyhydramnios
Premature rupture of membranes
Placental abruption
Scarred uterus
Total duration of labor
First stage of labor - Latent phase
First stage of labor - Active phase
Second stage of labor
Third stage of labor
Prolonged
Normal
Yes
No
Newborn weight (grams)
2500-4000
<2500
>4000
Placental retention/Placenta accreta /Placental implantation
Analgesia during labor
Instrumental assistance in delivery
Lacerations of the cervix, vagina, or perineum
Total Points
Risk of Death
B
Points
Ethnicity
Manchu
Han
Other
Occupation
Heavy physical labor
Light physical labor
Moderate physical labor
Unemployed
Pre-pregnancy BMI (Kg/m2)
<18.5 (Underweight)
>28.0 (Obesity)
18.5-23.9 (Normal)
24.0-27.9 (Overweight)
Parity (number of deliveries)
≥2
Gestational Age at Delivery (weeks)
38-40
<38
>40
Diabetes
Hypertension
Anemia
Uterine fibroids/adenomyosis
Polyhydramnios
Premature rupture of membranes
Placental abruption
Scarred uterus
First stage of labor - Latent phase
First stage of labor - Active phase
Second stage of labor
Prolonged
Normal
Yes
No
Newborn weight (grams)
2500-4000
<2500
>4000
Placental retention/Placenta accreta /Placental implantation
Analgesia during labor
Total Points
Risk of Death


A
Dxy 0.614
C (ROC) 0.807
R2 0.246
D 0.099
U 0.000
Q 0.099
Brier 0.050
Intercept 0.000
Slope 1.000
Emax 0.037
E90 0.007
Eavg 0.004
S:z −0.486
S:p 0.627
B
Dxy 0.587
C (ROC) 0.793
R2 0.203
D 0.068
U 0.000
Q 0.068
Brier 0.040
Intercept 0.000
Slope 1.000
Emax 0.023
E90 0.006
Eavg 0.003
S:z −0.261
S:p 0.794
C
Dxy 0.592
C (ROC) 0.796
R2 0.143
D 0.016
U 0.000
Q 0.016
Brier 0.010
Intercept 0.000
Slope 1.000
Emax 0.047
E90 0.003
Eavg 0.001
S:z 0.104
S:p 0.917
D
Dxy 0.869
C (ROC) 0.934
R2 0.477
D 0.031
U 0.000
Q 0.032
Brier 0.004
Intercept 0.000
Slope 1.000
Emax 0.103
E90 0.000
Eavg 0.001
S:z −0.522
S:p 0.601
E
Dxy 0.665
C (ROC) 0.833
R2 0.250
D 0.011
U 0.000
Q 0.011
Brier 0.003
Intercept 0.000
Slope 1.000
Emax 0.115
E90 0.001
Eavg 0.001
S:z −0.139
S:p 0.890
F
Dxy 0.607
C (ROC) 0.803
R2 0.244
D 0.098
U 0.000
Q 0.098
Brier 0.051
Intercept 0.002
Slope 0.998
Emax 0.058
E90 0.008
Eavg 0.004
S:z −0.211
S:p 0.833
G
Dxy 0.563
C (ROC) 0.782
R2 0.184
D 0.063
U 0.000
Q 0.063
Brier 0.043
Intercept −0.073
Slope 0.951
Emax 0.175
E90 0.007
Eavg 0.005
S:z 1.123
S:p 0.261
H
Dxy 0.478
C (ROC) 0.739
R2 0.083
D 0.008
U 0.001
Q 0.007
Brier 0.008
Intercept −0.874
Slope 0.836
Emax 0.291
E90 0.003
Eavg 0.003
S:z −1.338
S:p 0.181
I
Dxy 0.884
C (ROC) 0.942
R2 0.492
D 0.035
U 0.000
Q 0.036
Brier 0.004
Intercept 0.136
Slope 1.000
Emax 0.176
E90 0.002
Eavg 0.002
S:z 0.531
S:p 0.595
J
Dxy 0.608
C (ROC) 0.804
R2 0.261
D 0.008
U 0.000
Q 0.008
Brier 0.002
Intercept 0.612
Slope 1.188
Emax 0.567
E90 0.003
Eavg 0.002
S:z −1.258
S:p 0.208
K
Dxy 0.624
C (ROC) 0.812
R2 0.260
D 0.105
U 0.000
Q 0.105
Brier 0.049
Intercept 0.111
Slope 1.049
Emax 0.157
E90 0.007
Eavg 0.006
S:z −0.672
S:p 0.502
L
Dxy 0.589
C (ROC) 0.795
R2 0.205
D 0.070
U 0.000
Q 0.070
Brier 0.042
Intercept 0.090
Slope 1.018
Emax 0.095
E90 0.011
Eavg 0.005
S:z 0.350
S:p 0.727
M
Dxy 0.634
C (ROC) 0.817
R2 0.144
D 0.015
U 0.000
Q 0.016
Brier 0.010
Intercept 0.249
Slope 1.057
Emax 0.091
E90 0.011
Eavg 0.003
S:z 0.212
S:p 0.832
N
Dxy 0.850
C (ROC) 0.925
R2 0.459
D 0.034
U 0.000
Q 0.034
Brier 0.004
Intercept 0.046
Slope 0.966
Emax 0.181
E90 0.001
Eavg 0.002
S:z 0.461
S:p 0.645
O
Dxy 0.329
C (ROC) 0.665
R2 0.049
D 0.001
U 0.000
Q 0.001
Brier 0.002
Intercept −1.697
Slope 0.743
Emax 0.114
E90 0.002
Eavg 0.002
S:z −1.198
S:p 0.231
Ideal
Nonparametric
Actual Probability
Predicted Probability


A
Net benefit
Threshold probability
None
All
predict
B
Net benefit
Threshold probability
None
All
predict
C
Net benefit
Threshold probability
None
All
predict
D
Net benefit
Threshold probability
None
All
predict
E
Net benefit
Threshold probability
None
All
predict

Supplemental Table 1 Results of Predict Factors Selection for the Multivariate Logistic Regression Model in the Training Dataset for Postpartum Hemorrhage (PPH) and Its Subgroups

特征	PPH			UA-PPH			PF-PPH			CF-PPH			CA-PPH		
	OR	**95% CI**	***P***	**OR**	**95% CI**	***P***	**OR**	**95% CI**	***P***	**OR**	**95% CI**	***P***	**OR**	**95% CI**	***P***
General view															
Age (years)															
<25	Ref.			Ref.											
25-29	0.94	0.67, 1.35	0.746	1.04	0.70, 1.59	0.852									
30-34	1.28	0.91, 1.84	0.166	1.41	0.95, 2.16	0.099									
≥35	1.22	0.81, 1.85	0.349	1.25	0.78, 2.03	0.369									
Ethnicity															
Han	Ref.			Ref.			Ref.			Ref.					
Manchu	1.82	1.46, 2.24	***<0.001*****	1.59	1.24, 2.02	***<0.001*****	2.02	1.27, 3.08	***0.002****	1.53	0.63, 3.32	0.313			
Other ethnic groups	1.77	1.25, 2.45	***<0.001*****	1.75	1.20, 2.50	***0.003****	1.47	0.57, 3.11	0.361	3.01	1.10, 7.15	***0.020****			
Educational Attainment															
High school or below															
Bachelor's degree															
Postgraduate or higher															
Occupation															
Unemployed	Ref.			Ref.			Ref.						Ref.		
Light physical labor	1.05	0.86, 1.27	0.647	1.12	0.91, 1.38	0.283	0.72	0.44, 1.13	0.171				1.48	0.68, 3.01	0.294
Moderate physical labor	0.52	0.45, 0.61	***<0.001*****	0.53	0.45, 0.64	***<0.001*****	0.43	0.29, 0.61	***<0.001*****				0.66	0.34, 1.25	0.213
Heavy physical labor	0.31	0.17, 0.53	***<0.001*****	0.34	0.17, 0.61	***<0.001*****	0.29	0.05, 0.94	0.090				0.44	0.02, 2.47	0.453
Family Per Capita Monthly Income															

(10,000 yuan)															
<0.5															
0.5-2.0															
2.0-5.0															
>5.0															
Pre-pregnancy BMI （Kg/m²）															
<18.5（Underweight）	Ref.			Ref.			Ref.			Ref.			Ref.		
18.5-23.9（Normal）	1.00	0.86, 1.17	0.999	0.88	0.74, 1.04	0.139	1.15	0.80, 1.68	0.457	1.64	0.85, 3.18	0.155	2.99	1.43, 7.12	***0.007****
24.0-27.9（Overweight）	1.91	1.50, 2.41	***<0.001*****	1.68	1.29, 2.17	***<0.001*****	1.75	0.98, 3.04	0.051	5.26	2.16, 12.10	***<0.001*****	1.95	0.54, 6.36	0.279
>28.0（Obesity）	2.18	1.60, 2.94	***<0.001*****	1.51	1.04, 2.14	***0.024****	2.73	1.40, 5.03	***0.002****	7.56	3.02, 19.01	***<0.001*****	1.31	0.16, 6.40	0.770
Smoking															
No													Ref.		
Yes													10.20	1.61, 35.9	***0.002****
Alcohol Consumption															
No															
Yes															
Obstetric and Gynecologic History															
Parity (number of deliveries)															
0	Ref.			Ref.			Ref.			Ref.			Ref.		
1	0.27	0.20, 0.35	***<0.001*****	0.30	0.22, 0.40	***<0.001*****	0.32	0.15, 0.59	***<0.001*****	0.41	0.16, 0.93	0.050	0.30	0.07, 0.89	0.057
⩾2	0.88	0.33, 2.00	0.776	1.05	0.37, 2.51	0.912	1.40	0.08, 6.70	0.742	6.24	0.34, 33.10	0.084	5.52	0.29, 30.2	0.114

Gestational Age at Delivery (weeks)															
<38	Ref.			Ref.			Ref.								
38-40	1.56	1.12, 2.21	***0.010****	1.56	1.07, 2.35	***0.028****	1.77	0.86, 4.29	0.155						
>40	2.33	1.67, 3.32	***<0.001*****	2.42	1.66, 3.67	***<0.001*****	2.17	1.05, 5.29	0.057						
Diabetes															
No	Ref.			Ref.			Ref.			Ref.					
Yes	1.48	1.25, 1.76	***<0.001*****	1.40	1.15, 1.70	***<0.001*****	1.86	1.27, 2.66	***<0.001*****	1.62	0.82, 3.0[illegible]	0.143			
Hypertension															
No	Ref.			Ref.			Ref.			Ref.					
Yes	3.16	2.58, 3.84	***<0.001*****	3.23	2.60, 3.98	***<0.001*****	2.16	1.33, 3.37	***0.001****	2.44	1.13, 4.9[illegible]	***0.017****			
Anemia															
No	Ref.			Ref.			Ref.			Ref.			Ref.		
Yes	2.21	1.89, 2.58	***<0.001*****	2.06	1.72, 2.45	***<0.001*****	2.15	1.51, 3.02	***<0.001*****	2.11	1.18, 3.6[illegible]	***0.010****	1.81	1.03, 3.34	***0.049****
Coagulation disorder													Ref.		
No	Ref.												93.60	49.7, 174	***<0.001*****
Yes	3.31	1.98, 5.38	***<0.001*****										Ref.		
Uterine fibroids/adenomyosis															
No	Ref.			Ref.			Ref.			Ref.					
Yes	3.16	2.38, 4.16	***<0.001*****	3.07	2.25, 4.13	***<0.001*****	2.52	1.34, 4.38	***0.002****	3.66	1.24, 9.0[illegible]	***0.009****			
Polyhydramnios															
No	Ref.			Ref.			Ref.								
Yes	1.59	1.29, 1.95	***<0.001*****	1.55	1.22, 1.94	***<0.001*****	1.39	0.84, 2.19	0.181						

Premature rupture of membranes															
No	Ref.			Ref.			Ref.			Ref.			Ref.		
Yes	2.32	2.01, 2.68	***<0.001*****	2.18	1.85, 2.55	***<0.001*****	1.82	1.31, 2.51	***<0.001*****	1.33	0.77, 2.25	0.294	2.63	1.50, 4.59	***<0.001*****
Placental abruption															
No	Ref.			Ref.											
Yes	9.98	4.22, 22.51	***<0.001*****	11.00	4.66, 24.6	***<0.001*****									
Scarred uterus															
No	Ref.			Ref.									Ref.		
Yes	3.01	1.65, 5.18	***<0.001*****	2.96	1.55, 5.29	***<0.001*****							6.11	0.87, 24.5	***0.027****
Delivery Process and Neonatal Conditions															
Total duration of labor															
normal	Ref.			Ref.			Ref.			Ref.			Ref.		
prolonged	1.94	1.29, 2.88	***0.001****	1.50	0.97, 2.28	0.064	2.42	1.03, 5.01	***0.027****	5.16	2.01, 12.03	***<0.001*****	3.78	0.95, 11.2	***0.032****
First stage of labor - Latent phase															
normal	Ref.			Ref.											
prolonged	3.83	2.65, 5.48	***<0.001*****	4.42	3.02, 6.38	***<0.001*****									
First stage of labor - Active phase															
normal	Ref.			Ref.											
prolonged	3.17	2.30, 4.32	***<0.001*****	3.81	2.74, 5.24	***<0.001*****									
Second stage of labor															

normal	Ref.			Ref.			Ref.			Ref.					
prolonged	4.09	2.52, 6.52	***<0.001*** **	2.11	1.19, 3.59	***0.008*** *	3.42	1.20, 8.20	***0.011*** *	34.80	14.02, 83.10	***<0.001*** **			
Third stage of labor															
normal	Ref.						Ref.			Ref.					
prolonged	4.42	2.84, 6.76	***<0.001*** **				25.20	15.30, 40.41	***<0.001*** **	3.44	0.41, 13.52	0.114			
Placental retention/Placenta accreta/Placental implantation															
No	Ref.			Ref.			Ref.			Ref.			Ref.		
Yes	2.41	2.06, 2.80	***<0.001*** **	2.24	1.89, 2.65	***<0.001*** **	2.21	1.56, 3.10	***<0.001*** **	2.75	1.55, 4.76	***<0.001*** **	2.51	1.37, 4.47	***0.002*** *
Analgesia during labor															
No	Ref.			Ref.						Ref.			Ref.		
Yes	3.71	2.90, 4.72	***<0.001*** **	4.05	3.11, 5.21	***<0.001*** **				2.60	0.92, 6.40	0.052	4.63	1.90, 9.97	***<0.001*** **
Instrumental assistance in delivery															
No	Ref.									Ref.					
Yes	2.15	1.55, 2.93	***<0.001*** **							27.80	16.22, 48.03	***<0.001*** **			
Lacerations of the cervix, vagina, or perineum															
No	Ref.									Ref.					

Yes	1.47	1.19, 1.79	***<0.001****				36.10	21.00, 63.14	***<0.001****
Newborn weight (grams)									
<2500	Ref.			Ref.					
2500-4000	1.50	0.69, 4.00	0.358	3.30	1.02, 20.31	0.100			
>4000	8.50	3.79, 23.0	***<0.001****	15.10	4.57, 93.62	***<0.001****			

*: *P*<0.05; **: *P*<0.001; OR: Odds Ratio; CI: Confidence Interval;

BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-089734.R1
Article Type:	Original research
Date Submitted by the Author:	08-Nov-2024
Complete List of Authors:	Li, Jinke; Shengjing Hospital of China Medical University, Department of Obstetrics and Gynecology Zhang, Dandan; Shengjing Hospital of China Medical University, Department of Obstetrics and Gynecology Lin, Hong; Liaoning Maternal and Child Health Hospital, Department of Obstetrics and Gynecology Shao, Mengyuan; Shenyang Women's and Children's Hospital, Department of Obstetrics and Gynecology Wang, Xiaoxue; Shengjing Hospital of China Medical University, Department of Health Management Chen, Xueting; Shengjing Hospital of China Medical University, Department of Health Management Zhou, Yangzi; Shengjing Hospital of China Medical University, Department of Obstetrics and Gynecology Song, Zixuan; Shengjing Hospital of China Medical University, Department of Obstetrics and Gynecology
Primary Subject Heading:	Obstetrics and gynaecology
Secondary Subject Heading:	Obstetrics and gynaecology
Keywords:	Maternal medicine < OBSTETRICS, PERINATOLOGY, Postpartum Women < Postpartum Period, PREVENTIVE MEDICINE

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Postpartum Hemorrhage Following Vaginal Delivery: A Comprehensive Analysis and Development of Predictive Models for Etiological Subgroups in Chinese Women

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Abstract:

Objectives: This study aimed to dissect the etiological subgroups of postpartum hemorrhage (PPH) that occur after vaginal delivery in women with full-term singleton pregnancies. Our goal was to craft and validate predictive models to guide clinical decision-making and optimize resource allocation.

Design: A retrospective cohort study.

Setting: Shengjing Hospital of China Medical University, Liaoning Maternal and Child Health Hospital, and Shenyang Women's and Children's Hospital.

Participants: 29,842 women who underwent vaginal delivery were enrolled in the study across three hospitals from 2016 to 2022.

Primary outcome measures: PPH, categorized into uterine atony (UA), placental factors (PF), cervical trauma (CT), and coagulation abnormalities (CA) by etiology.

Results: The logistic regression for overall PPH and UA-PPH showcased high discrimination (AUCs of 0.807 and 0.794, respectively), coupled with commendable calibration and DCA-assessed clinical utility, culminating in the development of a nomogram for risk prediction. The PF-PPH model exhibited a modest AUC of 0.739, while the CT-PPH and CA-PPH models demonstrated suboptimal clinical utility and calibration.

Conclusions: The study identified factors associated with PPH and developed models with good performance for overall PPH and UA-PPH. The nomogram offers a valuable tool for risk prediction. However, models for PF-PPH, CT-PPH, and CA-PPH require further refinement. Future research should focus on larger samples and multi-center validation for enhanced model generalizability.

Keywords: Postpartum Hemorrhage, Vaginal Delivery, Etiological Subgroups, Predictive Models, nomogram

Strengths and limitations of this study

- This study included data from large multicenter cohorts in China, comprising 29,842 women to enhance the statistical power of the analysis.
- Predictive models were developed for postpartum hemorrhage following vaginal delivery and for different etiological subgroups.

- The predictive models were visualized using nomograms for clinical application.
- This study's test set is a single-center study specifically focused on vaginal delivery PPH, with a limited number of positive samples.
- The existing external validation datasets are from hospitals of the same region and level, resulting in a lack of diversification and generalizability.

Background

Postpartum hemorrhage (PPH) is defined as blood loss exceeding 500 milliliters within 24 hours following vaginal delivery or exceeding 1,000 milliliters within 24 hours following cesarean delivery.[1] PPH is a widespread and serious medical condition that poses significant risks to women's health around the world. It is particularly devastating in developing countries, where it is a principal contributor to maternal mortality.[2] It is estimated that approximately 1.4 million maternal deaths globally are tied to PPH each year, with the tragic loss of a woman's life to this condition occurring every four minutes.[3 4]. In Australia, the incidence of PPH increased from 6.3% in 2000 to 8.0% in 2009. [5] Similarly, in the United States, the rate of PPH rose from 2.7% in 1999 to 3.2% in 2014. [6] In China, despite a relatively lower maternal mortality rate of 17.8 per 100,000 in 2019, PPH accounted for one-quarter of these deaths.[7]

The World Health Organization (WHO) has conducted an analysis revealing that while PPH is a significant factor in maternal mortality and morbidity, the mortality rates vary considerably across different regions.[8] In high-income countries, the risk of death due to PPH is significantly lower than in low-income countries.[9] In high-income nations, the substantial blood loss primarily caused by PPH accounts for 13.4% of overall maternal mortality, while in Africa and Asia, this figure stands at 34% and 30.8%, respectively. [8] The international obstetric community is actively engaged in research to better understand the incidence, risk factors, and management strategies for PPH.[10-12]. Despite the establishment of global clinical guidelines and the identification of various risk factors, further exploration is needed to enhance our understanding and management of PPH.[13 14].

PPH can be etiologically classified into uterine atony (UA), placental factors (PF), cervical trauma (CT), and coagulation abnormalities (CA), each requiring distinct clinical management and treatment strategies. [15] Clear etiological classification is crucial for developing preventive strategies, formulating management plans, and rational allocation of medical resources.[16] While numerous cohort studies have focused on identifying risk factors for PPH, there is a scarcity of studies that quantify and weigh these risk factors for a comprehensive PPH risk assessment.[17 18] Given the complexity of PPH and the interplay of multiple risk factors, a holistic approach is necessary to accurately assess the risk of PPH.

Clinical prediction models (CPMs) have been widely applied in clinical settings in recent years. By constructing CPMs, physicians and patients can make better medical decisions, and health departments at all levels can allocate medical resources more rationally. These models play an irreplaceable role in primary prevention (assessing the quantitative risk of future diseases) and secondary prevention (constructing highly sensitive and specific diagnostic schemes, practicing "early detection, early diagnosis, early treatment"), reflecting significant health economic value.

There is a gap in research regarding the development of clinical prediction models for women specifically following vaginal delivery. Many studies are constrained by limited sample sizes, which can affect the robustness of the models[19]. Other research has focused on PPH prediction models for women undergoing cesarean sections.[20] Our study aims to address this gap by constructing a clinical prediction model tailored to PPH after vaginal delivery. By analyzing clinical data and risk factors through logistic regression, we can determine the relative impact of each factor on the likelihood of PPH. We further refine our model by performing secondary fitting based on the four etiological subgroups, creating a nomogram that enhances the precision of predicting high-risk populations for PPH. This work provides essential insights for the prevention and management of this critical condition.

Materials and methods

Data Sources and Ethics Statement

This cohort study was conducted at the obstetric wards of Shengjing Hospital of China Medical University, Liaoning Maternal and Child Health Hospital, and Shenyang Women's and Children's Hospital. The study population comprised women who underwent vaginal delivery between January 1, 2016, and December 31, 2022. The outcomes of interest were fetal birth outcomes within the first 24 hours postpartum. Inclusion criteria were women who consented to participate after being informed of the study's scope. Exclusion criteria were defined as follows: age under 18 or over 50 years, delivery occurring at less than 37 weeks or more than 42 weeks of gestation, multiple births, and instances of induced labor, stillbirth, or fetal death. Comprehensive data encompassing maternal characteristics, obstetric and gynecologic history, pregnancy complications, and details of the delivery process and neonatal conditions were collected (Supplement 1). To protect participant privacy, all data were anonymized. The study protocol was approved by the Ethical Review Committee of Shengjing Hospital of China Medical University (No. 2016PS344K), and written information about the study was provided to all participants.

Sample Size Calculation

According to the obstetric big data from Shengjing Hospital of China Medical University, the incidence of PPH is approximately 6%-7%. Based on the sample size estimation using the psamplesize package in R software, the minimum sample size required for constructing clinical prediction models is estimated to be between 1,048 and 1,536. The sample size included in this study far exceeds the minimum requirement.

Covariates

A range of covariates were taken into account, including:(1) Age, categorized as <25, 25-29, 30-34, and ≥35 years; (2) Ethnicity, divided into Han, Manchu, and other; (3) Education level, classified as high school or below, bachelor's degree, and postgraduate or above; (4) Occupation, categorized as unemployed, light physical labor, moderate physical labor, and heavy physical labor (based on the International Physical Activity Questionnaire, IPAQ); (5) Monthly household income per capita, divided into <0.5, 0.5-2.0, 2.0-5.0, and >5.0 thousand yuan; (6) Pre-pregnancy BMI, categorized as underweight (<18.5 kg/m^2), normal (18.5-23.9 kg/m^2), overweight (24-27.9 kg/m^2), and obese (≥28 kg/m^2); (7) Smoking and alcohol consumption history; (8) Gravidity, categorized as 1, 2, or ≥3 times; (9) Parity, divided into 0, 1, or ≥2 times; (10) History of miscarriage and induced labor; (11) Assisted reproductive technology; (11) Gestational age, categorized as <38, 38-40, and >40 weeks; (12) Pregnancy complications: diabetes, hypertension, anemia, coagulation disorder, uterine fibroids/adenomyosis, polyhydramnios, umbilical cord entanglement, premature rupture of membranes, placental abruption, vaginal bleeding during pregnancy, and scarred uterus; (13) Delivery time, divided into daytime (8-16), evening (17-23), and night (0-7) shifts; (14) Total duration of labor, categorized as normal (≤24 hours) and prolonged (>24 hours); (15) Latent phase of the first stage, categorized as normal (primiparous ≤20 hours, multiparous ≤14 hours) and prolonged (primiparous >20 hours, multiparous >14 hours); (16) Active phase of the first stage, categorized as normal (≤8 hours) and prolonged (>8 hours); (17) Second stage duration, categorized as normal and prolonged based on specific criteria for primiparous and multiparous women with or without analgesia; (18) Third stage duration, categorized as normal (≤30 minutes) and prolonged (>30 minutes); (19) Placental retention/placenta accreta/placental implantation; (20) Analgesia during labor; (21) Instrumental assistance in delivery; (22) Lacerations of the cervix, vagina, or perineum; (23) Newborn weight and length.

Etiology Subgroups

Patients were categorized into groups with or without postpartum hemorrhage based on the presence of postpartum bleeding and its underlying etiology, which included UA, PF, CT, and CA.

Model Construction

For the purpose of our investigation, we have categorized the participants from the Shengjing hospital of China Medical University as Cohort I. This cohort was systematically split into a training dataset and an internal validation dataset with a ratio of 7:3. The training dataset was instrumental in developing the predictive model, while the internal validation dataset served to assess the model's predictive accuracy. An additional cohort, comprising participants from two other hospitals, was designated as Cohort II. This external dataset was used to validate the model's general applicability and its efficacy in real-world clinical scenarios.

Within the confines of the datasets, we employed both univariate and multivariate logistic regression analyses to identify potential risk factors across various subgroups. These factors were then subjected to a rigorous selection process for inclusion in the predictive model. The selected factors were further analyzed using multivariate logistic regression (Bidirectional elimination) in training dataset to discern their discriminative power, thereby establishing them as predictive indicators for the model. The women in the training set were divided into PPH and non-PPH groups based on PPH as the outcome variable. Subsequently, they were further categorized by etiology into UA-PPH and non-UA-PPH groups, PF-PPH and non-PF-PPH groups, CT-PPH and non-CT-PPH groups, and CA-PPH and non-CA-PPH groups. Five predictive models were constructed sequentially, and the performance of these models was corroborated using both the test and validation datasets to ascertain the most accurate predictive model.

Evaluating the Performance of the Models

The area under the receiver operating characteristic curve (AUC) was the primary metric used to evaluate the discrimination of our models. An AUC value above 0.75 suggests excellent model discrimination, while an AUC below 0.6 indicates poor discrimination. Calibration curves were used to assess the models' accuracy, with closer alignment between observed and predicted incidence rates indicating higher model fidelity. Decision Curve Analysis (DCA) was also employed to evaluate the clinical utility of the models, offering a thorough assessment of the models' net benefits across various clinical scenarios.

Nomogram Development

Nomograms for postpartum hemorrhage and its four etiological subgroups were crafted to offer a visual representation of the risk scores derived from the logistic regression analysis. This tool simplifies the interpretation of complex statistical outcomes, providing a more straightforward approach to understanding risk assessments.

Statistical Analysis

All statistical computations, construction of traditional logistic models, and calculations of model discrimination and calibration were carried out using R version 3.6.3 from the R Foundation for Statistical Computing, Vienna, Austria. This software facilitated the development of traditional logistic predictive models and their subsequent evaluation for discriminative power, calibration, and clinical utility. Continuous variables conforming to the normal distribution were expressed as the mean ± standard deviation (SD), while non-normally distributed continuous variables were presented as medians with interquartile ranges. Categorical data were analyzed using chi-square tests, and continuous variables were analyzed using ANOVA or Mann-Whitney tests, as appropriate. Variables were adjusted as dummy variables, and odds ratios (OR) with corresponding 95% confidence intervals (95% CI) were calculated using univariate and multivariate logistic regression analyses, with significance level set at $P < 0.05$.

Patient and public involvement

Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Results

From 2016 to 2022, a total of 27,389 patients underwent vaginal delivery at the Shengjing Hospital of China Medical University. Forty-two patients under 18 years of age or over 50 years old were excluded. Additionally, 2,456 patients with gestational age less than 37 weeks or more than 42 weeks at delivery, 6 patients with multiple births, and 52 patients with induced labor, stillbirth, or fetal death were also excluded. Ultimately, 24,833 patients met the inclusion criteria and were enrolled in the cohort. According to the inclusion and exclusion criteria, a total of 5,099 patients in cohort II were included in the external validation dataset. The general characteristics of all patients are presented in Table 1. All patients were followed up within 24 hours after delivery for neonatal outcomes, with a follow-up rate of 100%. The patient selection criteria flowchart is shown in Figure 1.

Comparison of Basic Characteristics and Risk Analysis for Postpartum Hemorrhage (PPH) and Its Subgroups

Based on the occurrence of postpartum hemorrhage, the parturients in cohort one were divided into two groups: the non-PPH group and the PPH group. Similarly, within the etiological subgroups, they were categorized into UA-PPH and non-UA-PPH groups, PF-PPH and non-PF-PPH groups, CT-PPH and non-CT-PPH groups, and CA-PPH and non-CA-PPH groups. The comparison of basic characteristics and analysis of risk factors for each group are presented in Supplementary Tables 1-5.

In the multivariate analysis of risk factors, apart from age, parity, pre-pregnancy BMI, anemia, premature rupture of membranes, and combined placenta retention/placenta accreta/placental implantation, other specific risk factors were found to be associated with specific etiologies of postpartum hemorrhage. For instance, polyhydramnios was associated with UA-PPH; analgesia during labor, instrumental assistance, and cervical/vaginal/perineal lacerations were associated with the occurrence of CT-PPH (Table 2).

Selection of Predictive Factors for PPH and Its Subgroups in the Training Dataset

Through random sampling of cohort one, 70% of the data (N=17,383) from parturients were used to form the training dataset, with the remaining approximately 30% (N=7,450) forming the internal validation dataset. Multivariate analysis of risk factors for PPH and its subgroups was performed again in the training dataset, with results presented in Supplemental Table 1. After selection, predictive models were constructed for each group using the selected risk factors.

Evaluation of Predictive Model Discrimination

The ROC curves were plotted using R software for the PPH group and its various subgroups across the training dataset, internal and external validation dataset.

The results indicated that the predictive models, namely PPH-Logistic, UA-PPH-Logistic, PF-PPH-Logistic, CT-PPH-Logistic, and CA-PPH-Logistic, demonstrated high discriminative power in the training dataset with AUCs of 0.807 (95% CI: 0.792-0.821), 0.794 (95% CI: 0.777-0.811), 0.796 (95% CI: 0.761-0.830), 0.935 (95% CI: 0.901-0.969), and 0.802 (95% CI: 0.769-0.892), respectively.(Figure 2A-E) However, the PF-PPH-Logistic model exhibited only moderate discrimination with an AUC of 0.739 (95% CI: 0.666-0.813) in the internal validation dataset. Furthermore, the CA-PPH-Logistic model showed significantly lower discrimination in the external validation dataset with an AUC of 0.662 (95% CI: 0.450-0.873), which was notably inferior to its performance in the training and test datasets. This discrepancy may be attributed to the lower proportion of patients with coagulation disorders causing PPH in the validation dataset.

Assessment of Predictive Model Calibration

Calibration curves for the PPH and its subgroups were plotted for the Logistic predictive model within the training dataset (Supplemental Figure 1A-E). The performance of the PF-PPH-Logistic, particularly the CT-PPH-Logistic, and CA-PPH-Logistic models was suboptimal in certain aspects, with lower calibration, as observed in the test and external validation datasets (Supplemental Figure 1 F-J, Supplemental Figure 1K-O).

Evaluation of Clinical Utility of Predictive Models

In the evaluation of clinical utility, the PPH-Logistic and UA-PPH-Logistic models demonstrated satisfactory performance across all datasets. However, the clinical utility of the PF-PPH-Logistic, CT-PPH-Logistic, and CA-PPH-Logistic models was found to be relatively poor. (Supplemental Figure 2A-O)

Nomogram Construction

Using R software, we constructed nomograms for PPH and UA-PPH, with the results presented in Figure 3A-B. Physicians can assess the risk probability of PPH occurrence by summing the individual scores on the nomogram. This practical tool aids in a more precise estimation of PPH risk, thereby enhancing clinical decision-making.

Discussion

Maternal mortality has emerged as a pivotal indicator in global maternal and child health, serving as a significant benchmark for assessing the socioeconomic status of nations. Consequently, the effective reduction, prevention, and improvement of conditions leading to maternal deaths have become a focal point for public health initiatives worldwide. Among the various causes of maternal mortality, PPH stands out as a preventable condition that has attracted considerable attention. [17 18] With the rise in global economic standards and the evolution of medical technologies, there has been an approximate 50% decrease in the worldwide maternal mortality rate between 1990 and 2015. In China, the maternal mortality rate has seen a dramatic reduction of 98.78%[21] since the establishment of the People's Republic of China. Despite these advancements, a substantial proportion of maternal deaths, estimated between 27% and 40%[22], remain avoidable due to a range of factors, including inadequate social and medical interventions. PPH is a critical area of focus within this context, and the prediction and prevention of PPH to reduce avoidable maternal mortality present a significant challenge on the global stage.

Early prediction or identification of PPH and timely preventive or intervention measures are extremely valuable, necessitating a clear understanding of the etiologies of PPH for targeted management. In this study, the predictive models developed for PPH and UA-PPH demonstrated excellent performance in effectively identifying high-risk populations. For women at high risk for UA-PPH, early cord clamping should be considered. After the placenta is delivered, uterine fundal massage can be performed, and oxytocin should be administered immediately to promote uterine contraction and reduce bleeding. If necessary, mechanical compression or uterine artery ligation can be employed for hemostasis. Overall, high-risk women for PPH should be closely monitored, and proactive interventions should be implemented, such as promoting uterine contractions, advising patients to avoid excessive straining that could cause lacerations, and timely correction of coagulopathy.

The advent of the big data era has brought new opportunities for the management of PPH. The era is characterized by the digitization and standardization of medical records, along with an increasing volume of data, which has ushered in an era of data-driven management and treatment for maternal care. Leveraging big data analytics for disease risk prediction can contribute to the reduction of avoidable maternal deaths.

A review of the literature reveals over 200 prognostic models in obstetrics, three of which are pertinent to PPH.[23] However, few models have been applied in routine clinical practice, and the majority of studies have not provided model formulas, hindering independent external validation. The earliest PPH prediction model, dating back to 1994, originated from a case-control study in Zimbabwe[24], where PPH was defined as blood loss exceeding 600 milliliters following an unassisted vaginal delivery. This study included 150 PPH patients and 299 patients with normal deliveries, with a low positive predictive value of less than 7% and only 35.0% of patients experiencing postpartum bleeding. Since then, approximately ten additional PPH prediction models have been published. These models have varied in focus, with some concentrating on the relationship between placenta previa and PPH, while others have included only vaginal deliveries[24-27] or cesarean sections[20 28 29], and some have targeted women with placental implantation disorders[30] or general obstetric populations[31]. PPH research has been conducted in hospitals across various countries, including Italy, China, France, the United States, the United Kingdom, South Korea, the Netherlands, Spain, Zimbabwe, Denmark, and Egypt. From the 14 published studies, a total of 124 independent variables were identified as potential predictors (ranging from 5 to 38 per study), and 64 variables were ultimately selected for the final models (an average of 5-15 factors per study). Common predictors included parity, low pre-pregnancy hemoglobin, antenatal bleeding, maternal age over 35, gestational age, high neonatal weight, multiple pregnancies, body mass index (BMI) over 25, previous cesarean section, anterior placenta, and retained placenta. These predictors have also been incorporated into our predictive model.

Once a clinical prediction model is developed, it must undergo validation and evaluation to assess the model's effectiveness, reproducibility, and portability. Published PPH prediction models have reported AUCs ranging from 0.70[25] to 0.90[27], with external validation AUCs of 0.83[20], which are comparable to the results of our study. In addition to discrimination, calibration is essential to evaluate the consistency between the predicted probabilities of clinical outcomes and the observed event probabilities. Only a few studies, such as one by Albright in 2019 on the prediction of PPH following cesarean section, have utilized calibration curves[32], while most have employed the Hosmer-Lemeshow goodness-of-fit test to compare predicted probabilities with actual event probabilities for significant differences. The Hosmer-Lemeshow test, however, has limited efficacy in small-sample prediction models as it does not quantify model calibration[33 34]or provide direction or magnitude of mis calibration[35].

The Decision Curve Analysis (DCA)[35] has been used to evaluate the clinical utility of models, focusing on the selection of true positives from positive patients to avoid unnecessary medical resource consumption and reduce harm from overtreatment of false positives. DCA is particularly suited for scenarios where symptoms suggest the possibility of disease but a diagnosis has not yet been confirmed, guiding the decision on whether or what kind of screening method to adopt for disease diagnosis. The DCA's axes represent the threshold probability (P) and net benefit (NB), allowing for the determination of intervention measures based on the predicted probability of adverse events.[36]

In essence, both ROC and DCA can be used to assess the quality of predictive models, but they differ fundamentally in their theoretical constructs. While ROC combines sensitivity and specificity to compare the accuracy of predictive models through the AUC, the highest AUC does not necessarily represent the optimal model in clinical practice. For instance, in this study, patients in the CA-PPH group, due to coagulation disorders, all underwent cesarean section deliveries to minimize the number of false positives. This requires decision-makers to consider practical issues, as a high ROC does not always indicate the best treatment approach. Furthermore, for some extreme cases, the accuracy of ROC becomes less critical, and DCA evaluation results are needed for reference.

Statistical analysis of previously published PPH data has shown that factors such as general anesthesia in pregnant women, prolonged use of oxytocin, excessive uterine tension (multiple pregnancies, polyhydramnios), and chorioamnionitis are all associated with uterine atony, potentially increasing the risk of postpartum bleeding. Previous studies have suggested that for pregnant women with high-risk factors, assessing and selecting appropriate treatment options and management based on the type and weight of different risks can reduce the risk of adverse pregnancy outcomes or death[37]. Early prediction and intervention are key measures in reducing maternal mortality, with studies finding that timely interventions can effectively lower maternal mortality rates by 10%[38]. Establishing a model that predicts the risk of PPH following vaginal delivery and guides clinical practice is a significant task for maternal and child health.

Conclusion

In conclusion, our study has successfully developed and validated predictive models for PPH following vaginal delivery, offering a novel approach to risk assessment in this critical area of maternal health. The models, particularly for overall PPH and UA-PPH, demonstrated high discriminative power and clinical utility, with the nomogram providing a user-friendly tool for clinicians. Despite the promising results, limitations exist in the application of the PF-PPH, CT-PPH, and CA-PPH models due to the insufficient positive sample size in these subgroups. The generalizability of our findings may also be limited by the single-center nature of the study and the regional characteristics of the included hospitals. Future research should aim to expand the sample size and include multi-center data to improve the models' applicability and robustness. This study contributes to the growing body of evidence on PPH management and has the potential to influence policy and practice, ultimately enhancing maternal care and outcomes.

List of abbreviations

RP: Refined Peyton;

TTM: Traditional Teaching-mode

DOPS: direct observation of procedural skills

OB-GYN: Obstetrics and Gynecology

CBVI: computer-based video instruction

PEARLS: Promoting Excellence and Reflective Learning in Simulation

OSCE: objective structured clinical assessment

Declarations

Ethics approval and consent to participate

Ethics approval and consent to participate: The study was approved by the Ethics Committee of Shengjing Hospital of China Medical University (No. 2016PS344K, Date.17/12/2016). All participants provided informed consent.

Consent for publication

Not Applicable

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Competing interests

No potential conflict of interest was reported by the author(s).

Funding

This study was supported in part by grants from 345 Talent Project of Shengjing Hospital of China Medical University (No. M0946), and Medical Education Research Project of Liaoning Province (No. 2022-N005-03).

Authors' contributions

Contributors JL and DZ contributed equally to this study. JL, DZ and KZ designed the study and drafted the manuscript. HL, MS, and XW done the data collection. YZ and XC designed the statistical analysis plan. DZ has participated the training and reviewed and co-authored the manuscript with ZS. All authors have read and approved this manuscript. ZS is responsible for the overall content as guarantor.

Acknowledgements

We would like to express our gratitude to all those who helped us during the writing of this manuscript. Thanks to all the peer reviewers for their opinions and suggestions. We would like to acknowledge that Jinke Li and Dandan Zhang have contributed equally to this work.

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Table 1 The general view of the maternal.

Characteristics	Cohort population （N=24,833）	Validation population (N=5009)	P
Age (years) *，N（%）			0.393
<25	1,309 （5.27%）	266 (5.31%)	
25-29	11,736 （47.26%）	2340 (46.71%)	
30-34	9,445 （38.03%）	1959 (39.11%)	
⩾35	2,343 （9.44%）	444 (8.86%)	
Ethnicity，N（%）			0.983
Han	22,222 （89.49%）	4,475 (89%)	
Manchu	1,872 （7.54%）	389 (7.8%)	
Other ethnic groups	739 （2.98%）	145 (2.9%)	
Educational Attainment，N（%）			0.115
High school or below	8,635 （34.77%）	1,742 (35%)	
Bachelor's degree	13,639 （54.92%）	2,703 (54%)	
Postgraduate or higher	2,559 （10.30%）	564 (11%)	
Occupation，N（%）			0.777
Unemployed	11,373 （45.80%）	2,266 (45%)	
Light physical labor	2,825 （11.38%）	569 (11%)	
Moderate physical labor	10,011 （40.31%）	2,038 (41%)	
Heavy physical labor	624 （2.51%）	136 (2.7%)	
Family Per Capita Monthly Income (10,000 yuan)，N（%）			0.9862
<0.5	10,325 （41.58%）	2,080 (42%)	
0.5-2.0	9,534 （38.39%）	1,922 (38%)	
2.0-5.0	3,584 （14.43%）	720 (14%)	
>5.0	1,390 （5.60%）	287 (5.7%)	
Pre-pregnancy BMI （Kg/m2） *，N（%）			<0.001
<18.5（Underweight）	7,294 （29.37%）	1475 (29.45%)	
18.5-23.9（Normal）	15,005 （60.42%）	2963 (59.16%)	
24.0-27.9（Overweight）	1,700 （6.85%）	307 (6.13%)	
>28.0（Obesity）	834 （3.36%）	264 (5.29%)	
Pregnancy History，N（%）			0.565
1	14,985 （60.34%）	3,005 (60%)	
2	6,513 （26.23%）	1,303 (26%)	
⩾3	3,335 （13.43%）	701 (14%)	
Parity (number of deliveries)，N（%）			0.775
0	20,550 （82.75%）	4,127 (82%)	
1	4,152 （16.72%）	853 (17%)	
⩾2	131 （0.53%）	29 (0.6%)	
Gestational Age at Delivery (weeks)，N（%）			0.434

<38	1,507 （6.07%）	296 （5.91%）	
38-40	13,023 （52.44%）	2589 （51.59%）	
>40	10,303 （41.49%）	2129 （42.50%）	
Blood Loss（ml）	393.54±92.53	413.48±124.65	0.081
Postpartum Hemorrhage，N（%）	1,623 （6.54%）	286 （5.71%）	0.032
Due to uterine atony，N（%）	1,225 （4.93%）	266 （5.31%）	0.279
Due to placental factors，N（%）	242 （0.97%）	43 （0.86%）	0.489
Due to Cancal Trauma，N（%）	139 （0.56%）	31 （0.62%）	0.686
Due to coagulation disorders，N（%）	76 （0.31%）	17 （0.34%）	0.705

Table 2: Multivariate Risk Factor Analysis for Postpartum Hemorrhage (PPH) within Subgroups

Characteristics	PPH	UA-PPH	PF-PPH	CT-PPH	CA-PPH
General view					
Age (years)	*	*	-	-	-
Ethnicity	**	**	**	*	-
Educational Attainment	-	-	-	-	-
Occupation	**	**	**	-	*
Family Per Capita Monthly Income (10,000 yuan)	-	-	-	-	-
Pre-pregnancy BMI （Kg/m2）	**	**	**	**	*
Smoking	-	-	-	-	*
Alcohol Consumption	-	-	-	-	-
Obstetric and Gynecologic History					
Pregnancy History	-	-	-	-	-
Parity (number of deliveries)	**	**	**	*	*
History of miscarriage	-	-	-	-	-
Spontaneous abortion	-	-	-	-	-
Induced abortion or medication abortion	-	-	-	-	-
Induced labor	-	-	-	-	-
Assisted reproductive technology	-	-	-	-	-
Gestational Age at Delivery (weeks)	**	**	*	-	-
Diabetes	**	**	**	*	-
Hypertension	**	**	**	*	-
Anemia	**	**	**	**	*

Coagulation disorder	**	-	-	-	*
Uterine fibroids/adenomyosis	**	**	**	*	-
Polyhydramnios	**	**	*	-	-
Umbilical cord entanglement	-	-	-	-	-
Premature rupture of membranes	**	**	**	*	**
Placental abruption	**	**	-	-	-
Vaginal bleeding during pregnancy	-	-	-	-	-
Scarred uterus	**	**	-	-	*
		Delivery Process and Neonatal Conditions			
Time of delivery	-	-	-	-	-
Total duration of labor	**	*	*	*	**
First stage of labor - Latent phase	**	**	-	-	-
First stage of labor - Active phase	**	**	-	-	-
Second stage of labor	**	**	*	**	-
Third stage of labor	**	-	**	*	-
Placental retention/Placenta accreta/Placental implantation	**	**	**	**	**
Analgesia during labor	**	**	-	*	**
Instrumental assistance in delivery	**	-	-	**	-
Lacerations of the cervix, vagina, or perineum	**	-	-		-
Newborn weight (grams)	**	**	-	-	-
Newborn length (centimeters)	-	-	-	-	-

*: *P*<0.05; **: *P*<0.001

Figure legend

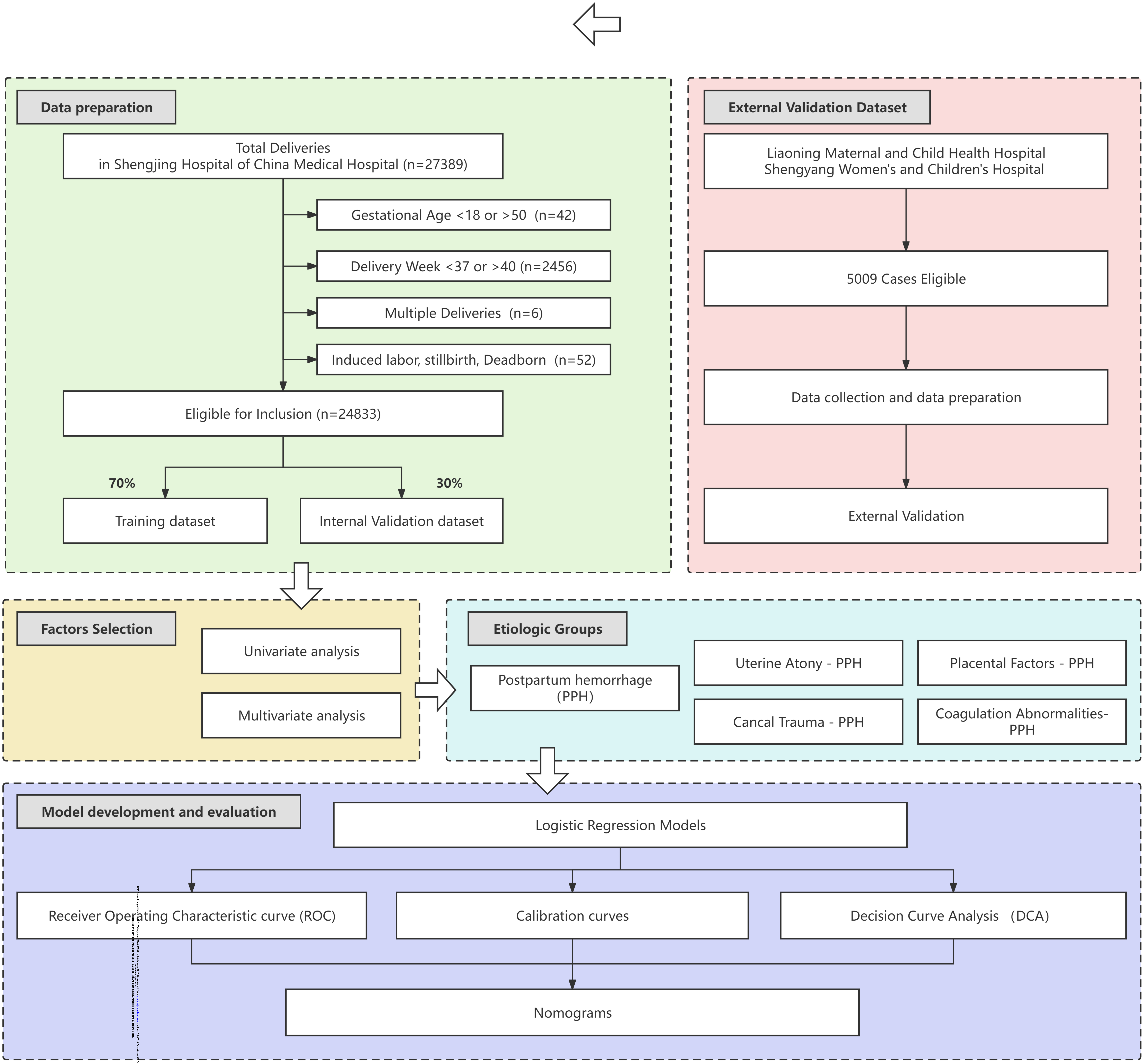
Figure 1. Patient Selection Criteria Flowchart.

Figure 2. AUC Curve for Postpartum Hemorrhage (PPH) Group and four subgroups. A. PPH Group; B. Uterine Atony PPH Group; C. Placental Factors PPH Group; D. Cervical Trauma PPH Group; E. Coagulation Abnormalities PPH Group. The blue line signifies the training dataset, which is employed to evaluate the model's predictive capabilities following the training phases. The green line corresponds to the internal validation dataset, pivotal for refining model parameters and for conducting initial assessments of the model's accuracy. The purple line denotes the external validation dataset, which is utilized to ascertain the model's generalizability and to verify its performance in an independent dataset.

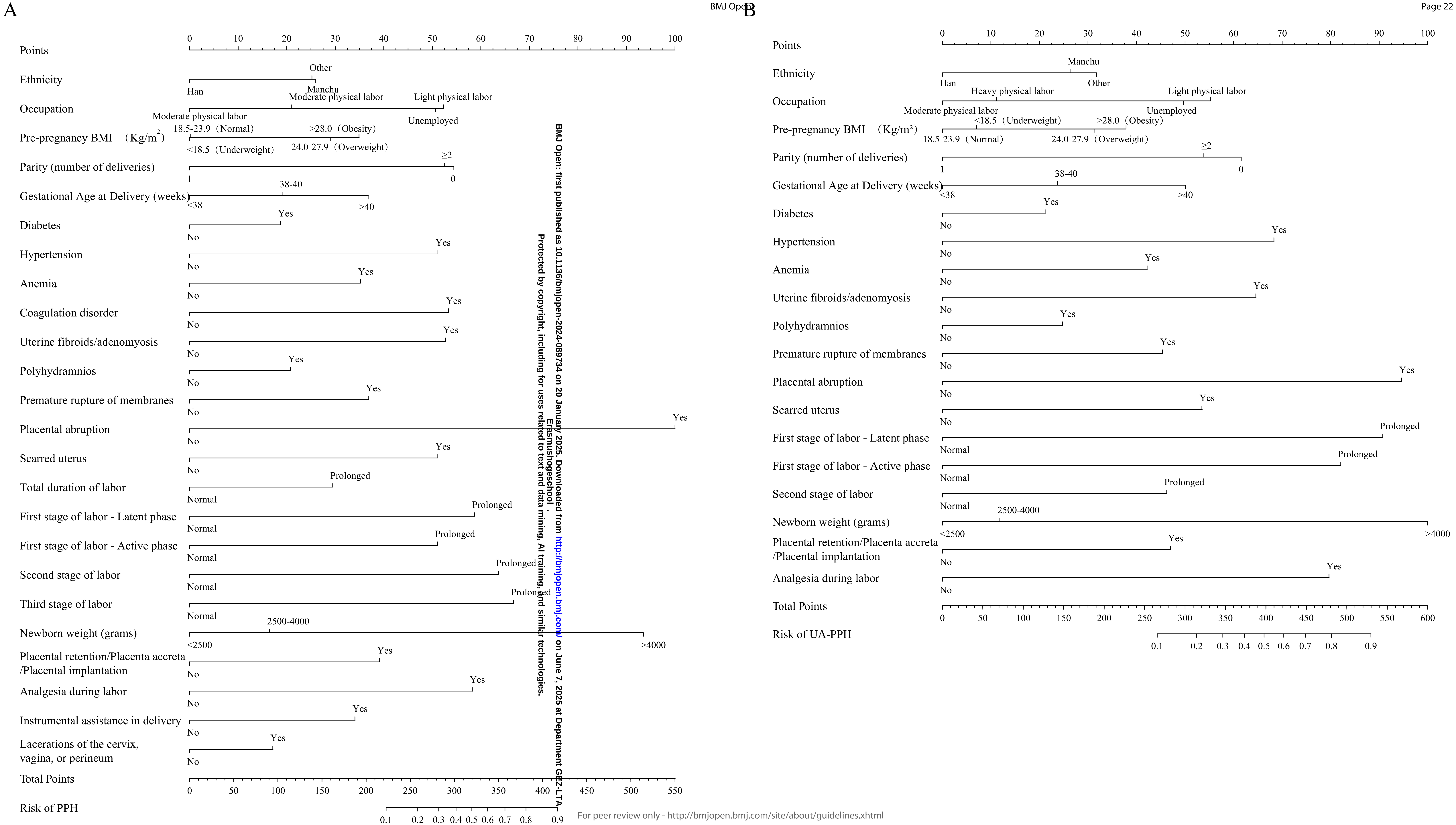
Figure 3. Nomograms for Postpartum Hemorrhage (PPH) and Uterine Atony PPH Group. A. PPH Group; B. Uterine Atony PPH Group.

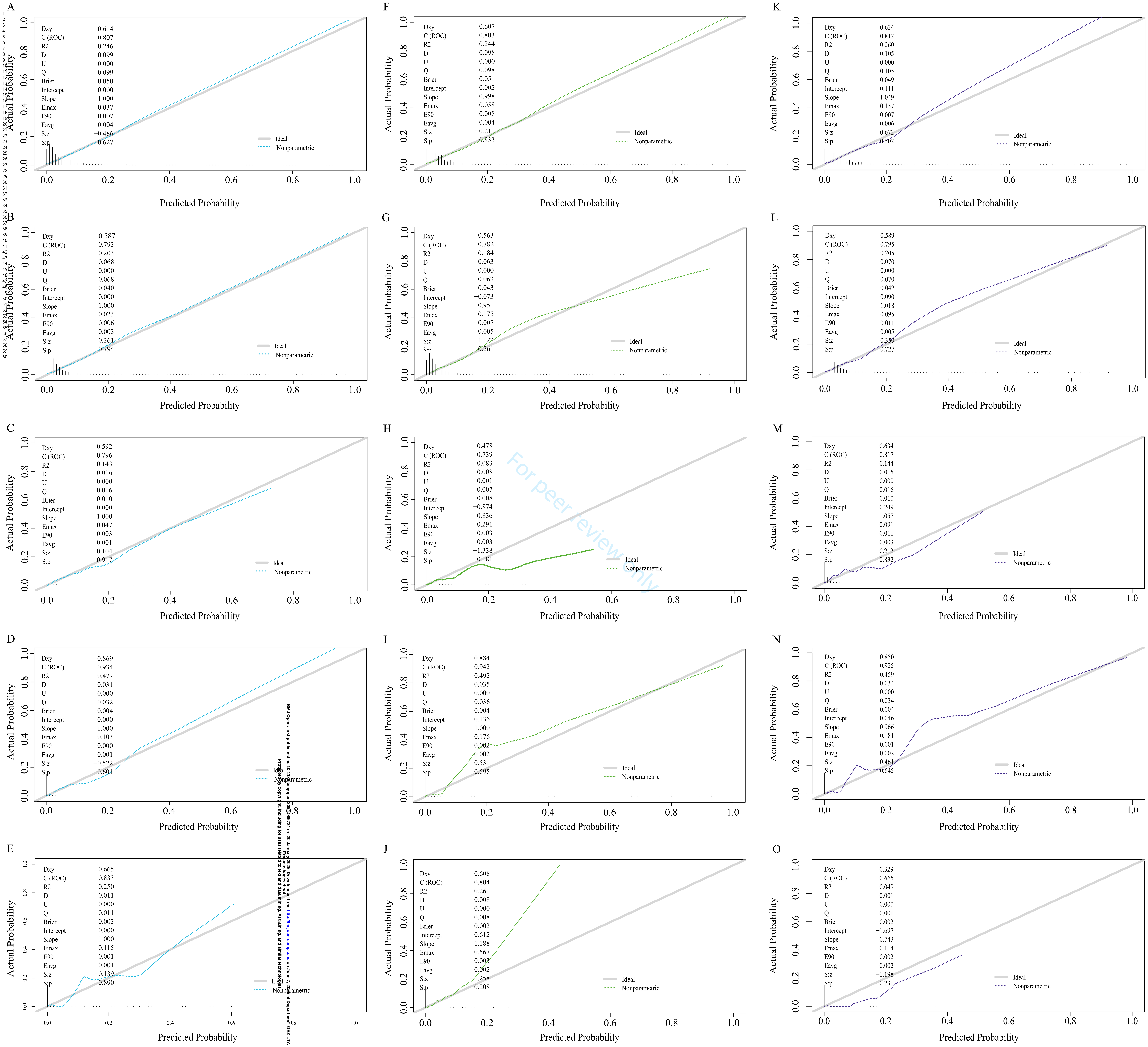
Supplemental Figure 1. Calibration curves for Postpartum Hemorrhage (PPH) Group and four subgroups. A\F\K. PPH Group; B\G\L. Uterine Atony PPH Group; C\H\M. Placental Factors PPH Group; D\I\N. Cervical Trauma PPH Group; E\J\O. Coagulation Abnormalities PPH Group. The blue line signifies the training dataset; The green line signifies the internal validation dataset; The purple line signifies the external validation dataset.

Supplemental Figure 2. Decision Curve Analysis for Postpartum Hemorrhage (PPH) Group and four subgroups. A. PPH Group; B. Uterine Atony PPH Group; C. Placental Factors PPH Group; D. Cervical Trauma PPH Group; E. Coagulation Abnormalities PPH Group. The blue line signifies the training dataset; The green line signifies the internal validation dataset; The purple line signifies the external validation dataset.

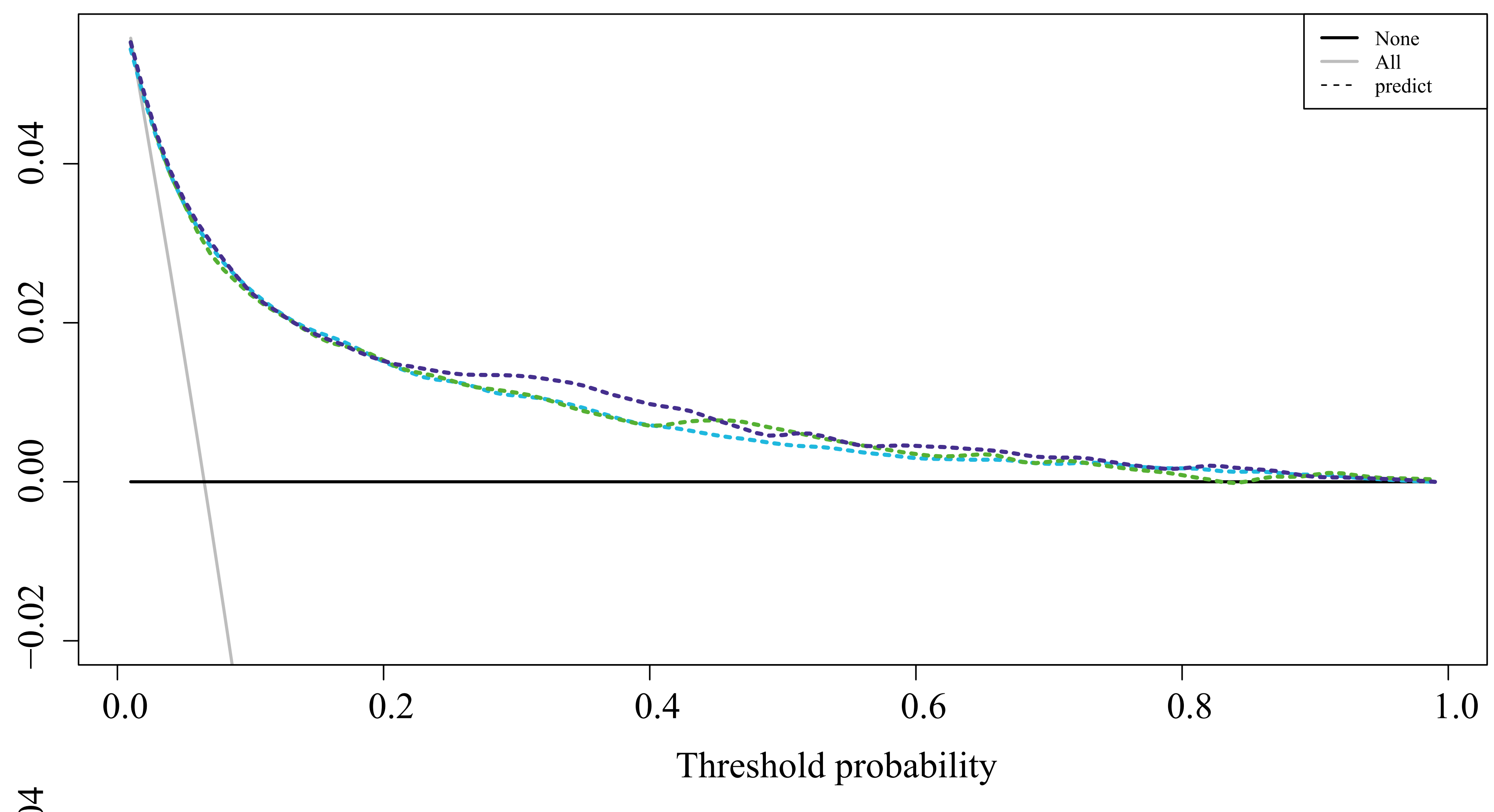

Data preparation
Total Deliveries
in Shengjing Hospital of China Medical Hospital (n=27389)
Gestational Age <18 or >50 (n=42)
Delivery Week <37 or >40 (n=2456)
Multiple Deliveries (n=6)
Induced labor, stillbirth, Deadborn (n=52)
Eligible for Inclusion (n=24833)
70%
30%
Training dataset
Internal Validation dataset
External Validation Dataset
Liaoning Maternal and Child Health Hospital
Shengyang Women's and Children's Hospital
5009 Cases Eligible
Data collection and data preparation
External Validation
Factors Selection
Univariate analysis
Multivariate analysis
Etiologic Groups
Postpartum hemorrhage (PPH)
Uterine Atony - PPH
Placental Factors - PPH
Cancal Trauma - PPH
Coagulation Abnormalities-PPH
Model development and evaluation
Logistic Regression Models
Receiver Operating Characteristic curve (ROC)
Calibration curves
Decision Curve Analysis (DCA)
Nomograms


A
Sensitivity
Specificity
AUC: 0.807 (0.792–0.821)
AUC: 0.803 (0.781–0.825)
AUC: 0.812 (0.786–0.838)
B
Sensitivity
Specificity
AUC: 0.794 (0.777–0.811)
AUC: 0.782 (0.756–0.807)
AUC: 0.795 (0.764–0.825)
C
Sensitivity
Specificity
AUC: 0.796 (0.761–0.830)
AUC: 0.739 (0.666–0.813)
AUC: 0.816 (0.750–0.882)
D
Sensitivity
Specificity
AUC: 0.935 (0.901–0.969)
AUC: 0.943 (0.903–0.982)
AUC: 0.926 (0.869–0.982)
E
Sensitivity
Specificity
AUC: 0.831 (0.769–0.892)
AUC: 0.802 (0.655–0.950)
AUC: 0.662 (0.450–0.873)

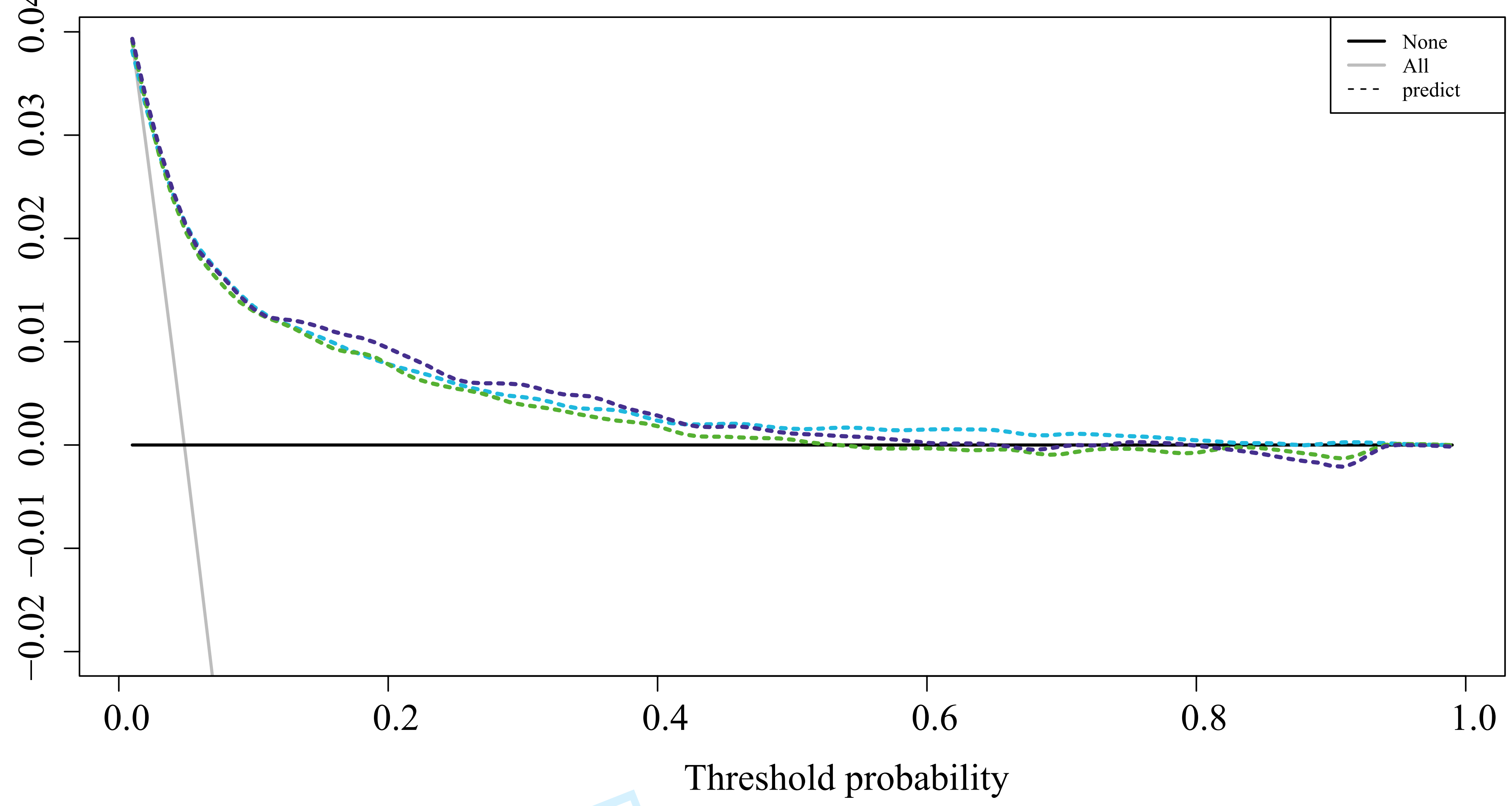

A
Points
0 10 20 30 40 50 60 70 80 90 100
Ethnicity
Han
Other
Manchu
Occupation
Moderate physical labor
Light physical labor
Unemployed
Pre-pregnancy BMI (Kg/m2)
Moderate physical labor
18.5-23.9 (Normal)
>28.0 (Obesity)
<18.5 (Underweight)
24.0-27.9 (Overweight)
Parity (number of deliveries)
≥2
1
0
Gestational Age at Delivery (weeks)
38-40
<38
>40
Diabetes
Hypertension
Anemia
Coagulation disorder
Uterine fibroids/adenomyosis
Polyhydramnios
Premature rupture of membranes
Placental abruption
Scarred uterus
Yes
No
Total duration of labor
First stage of labor - Latent phase
First stage of labor - Active phase
Second stage of labor
Third stage of labor
Prolonged
Normal
Newborn weight (grams)
2500-4000
<2500
>4000
Placental retention/Placenta accreta /Placental implantation
Analgesia during labor
Instrumental assistance in delivery
Lacerations of the cervix, vagina, or perineum
Total Points
0 50 100 150 200 250 300 350 400 450 500 550
Risk of PPH
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
B
Points
0 10 20 30 40 50 60 70 80 90 100
Ethnicity
Manchu
Han
Other
Occupation
Heavy physical labor
Light physical labor
Moderate physical labor
Unemployed
Pre-pregnancy BMI (Kg/m2)
<18.5 (Underweight)
>28.0 (Obesity)
18.5-23.9 (Normal)
24.0-27.9 (Overweight)
Parity (number of deliveries)
≥2
1
0
Gestational Age at Delivery (weeks)
38-40
<38
>40
Diabetes
Hypertension
Anemia
Uterine fibroids/adenomyosis
Polyhydramnios
Premature rupture of membranes
Placental abruption
Scarred uterus
Yes
No
First stage of labor - Latent phase
First stage of labor - Active phase
Second stage of labor
Prolonged
Normal
Newborn weight (grams)
2500-4000
<2500
>4000
Placental retention/Placenta accreta /Placental implantation
Analgesia during labor
Total Points
0 50 100 150 200 250 300 350 400 450 500 550 600
Risk of UA-PPH
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9


A
Dxy 0.614
C (ROC) 0.807
R2 0.246
D 0.099
U 0.000
Q 0.099
Brier 0.050
Intercept 0.000
Slope 1.000
Emax 0.037
E90 0.007
Eavg 0.004
S:z −0.486
S:p 0.627
Ideal
Nonparametric
Actual Probability
Predicted Probability
B
Dxy 0.587
C (ROC) 0.793
R2 0.203
D 0.068
U 0.000
Q 0.068
Brier 0.040
Intercept 0.000
Slope 1.000
Emax 0.023
E90 0.006
Eavg 0.003
S:z −0.261
S:p 0.794
Ideal
Nonparametric
Actual Probability
Predicted Probability
C
Dxy 0.592
C (ROC) 0.796
R2 0.143
D 0.016
U 0.000
Q 0.016
Brier 0.010
Intercept 0.000
Slope 1.000
Emax 0.047
E90 0.003
Eavg 0.001
S:z 0.104
S:p 0.917
Ideal
Nonparametric
Actual Probability
Predicted Probability
D
Dxy 0.869
C (ROC) 0.934
R2 0.477
D 0.031
U 0.000
Q 0.032
Brier 0.004
Intercept 0.000
Slope 1.000
Emax 0.103
E90 0.000
Eavg 0.001
S:z −0.522
S:p 0.601
Ideal
Nonparametric
Actual Probability
Predicted Probability
E
Dxy 0.665
C (ROC) 0.833
R2 0.250
D 0.011
U 0.000
Q 0.011
Brier 0.003
Intercept 0.000
Slope 1.000
Emax 0.115
E90 0.001
Eavg 0.001
S:z −0.139
S:p 0.890
Ideal
Nonparametric
Actual Probability
Predicted Probability
F
Dxy 0.607
C (ROC) 0.803
R2 0.244
D 0.098
U 0.000
Q 0.098
Brier 0.051
Intercept 0.002
Slope 0.998
Emax 0.058
E90 0.008
Eavg 0.004
S:z −0.211
S:p 0.833
Ideal
Nonparametric
Actual Probability
Predicted Probability
G
Dxy 0.563
C (ROC) 0.782
R2 0.184
D 0.063
U 0.000
Q 0.063
Brier 0.043
Intercept −0.073
Slope 0.951
Emax 0.175
E90 0.007
Eavg 0.005
S:z 1.123
S:p 0.261
Ideal
Nonparametric
Actual Probability
Predicted Probability
H
Dxy 0.478
C (ROC) 0.739
R2 0.083
D 0.008
U 0.001
Q 0.007
Brier 0.008
Intercept −0.874
Slope 0.836
Emax 0.291
E90 0.003
Eavg 0.003
S:z −1.338
S:p 0.181
Ideal
Nonparametric
Actual Probability
Predicted Probability
I
Dxy 0.884
C (ROC) 0.942
R2 0.492
D 0.035
U 0.000
Q 0.036
Brier 0.004
Intercept 0.136
Slope 1.000
Emax 0.176
E90 0.002
Eavg 0.002
S:z 0.531
S:p 0.595
Ideal
Nonparametric
Actual Probability
Predicted Probability
J
Dxy 0.608
C (ROC) 0.804
R2 0.261
D 0.008
U 0.000
Q 0.008
Brier 0.002
Intercept 0.612
Slope 1.188
Emax 0.567
E90 0.003
Eavg 0.002
S:z −1.258
S:p 0.208
Ideal
Nonparametric
Actual Probability
Predicted Probability
K
Dxy 0.624
C (ROC) 0.812
R2 0.260
D 0.105
U 0.000
Q 0.105
Brier 0.049
Intercept 0.111
Slope 1.049
Emax 0.157
E90 0.007
Eavg 0.006
S:z −0.672
S:p 0.502
Ideal
Nonparametric
Actual Probability
Predicted Probability
L
Dxy 0.589
C (ROC) 0.795
R2 0.205
D 0.070
U 0.000
Q 0.070
Brier 0.042
Intercept 0.090
Slope 1.018
Emax 0.095
E90 0.011
Eavg 0.005
S:z 0.350
S:p 0.727
Ideal
Nonparametric
Actual Probability
Predicted Probability
M
Dxy 0.634
C (ROC) 0.817
R2 0.144
D 0.015
U 0.000
Q 0.016
Brier 0.010
Intercept 0.249
Slope 1.057
Emax 0.091
E90 0.011
Eavg 0.003
S:z 0.212
S:p 0.832
Ideal
Nonparametric
Actual Probability
Predicted Probability
N
Dxy 0.850
C (ROC) 0.925
R2 0.459
D 0.034
U 0.000
Q 0.034
Brier 0.004
Intercept 0.046
Slope 0.966
Emax 0.181
E90 0.001
Eavg 0.002
S:z 0.461
S:p 0.645
Ideal
Nonparametric
Actual Probability
Predicted Probability
O
Dxy 0.329
C (ROC) 0.665
R2 0.049
D 0.001
U 0.000
Q 0.001
Brier 0.002
Intercept −1.697
Slope 0.743
Emax 0.114
E90 0.002
Eavg 0.002
S:z −1.198
S:p 0.231
Ideal
Nonparametric
Actual Probability
Predicted Probability

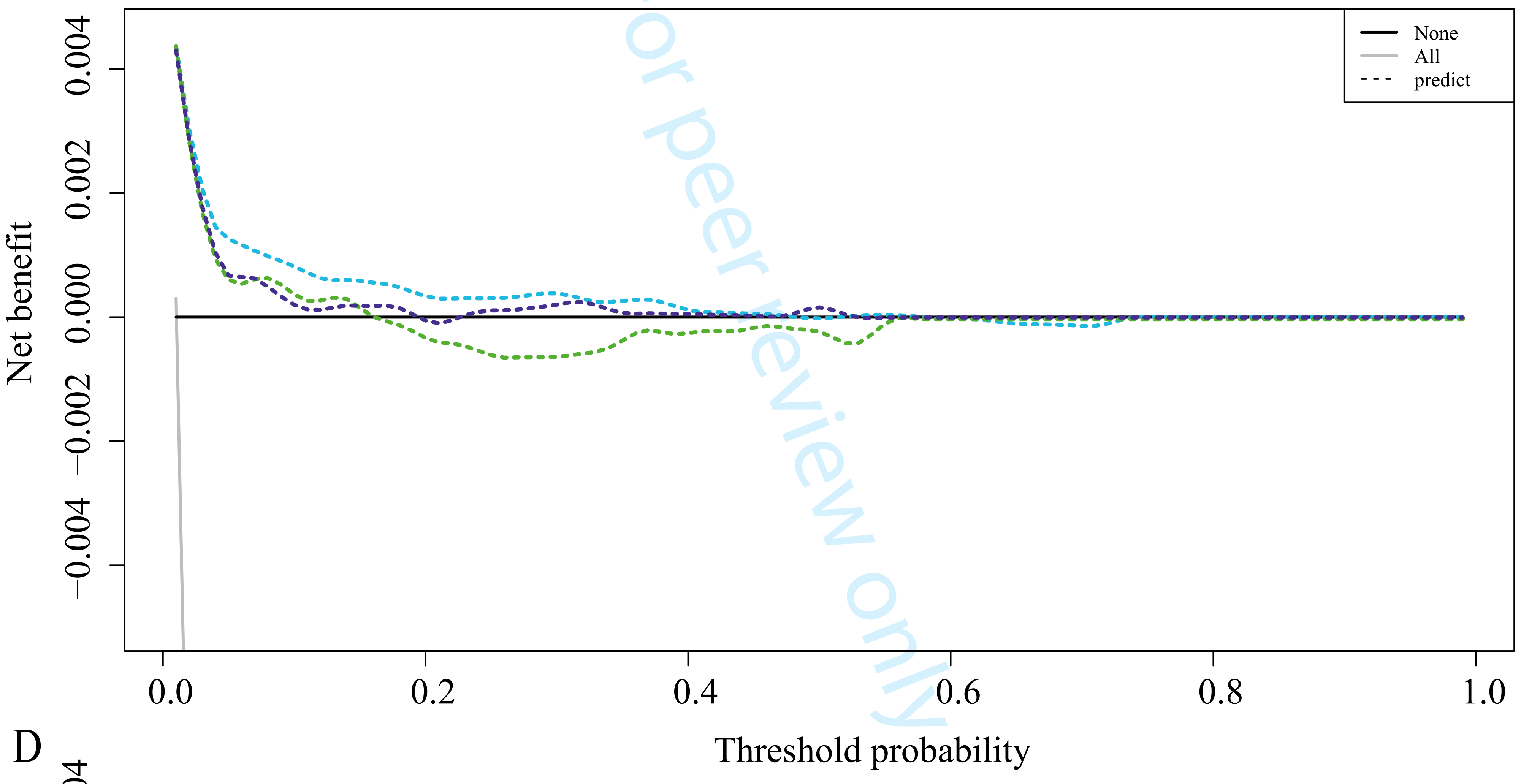
A


None
All
predict
Net benefit
Threshold probability

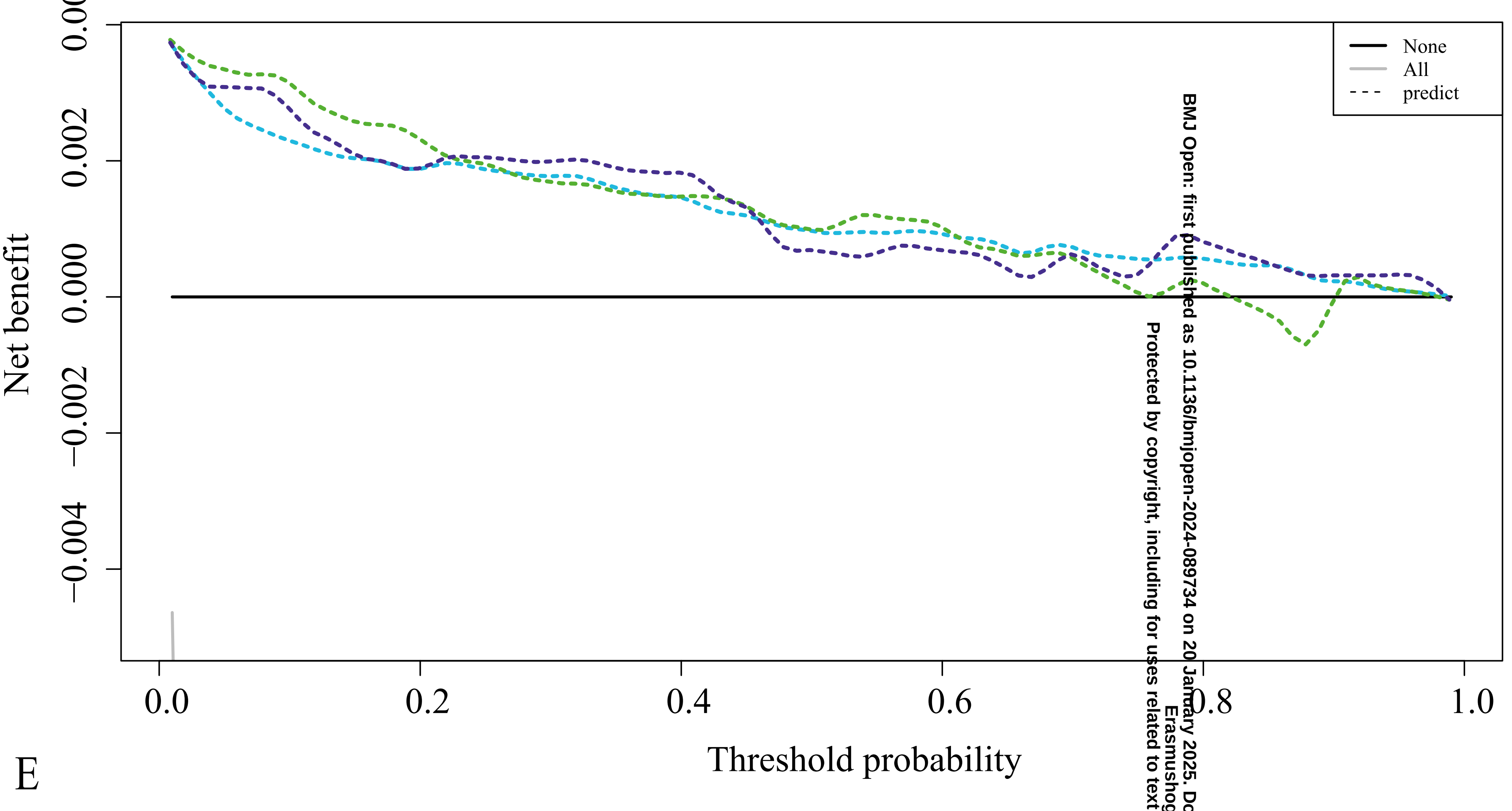
B


None
All
predict
Net benefit
Threshold probability

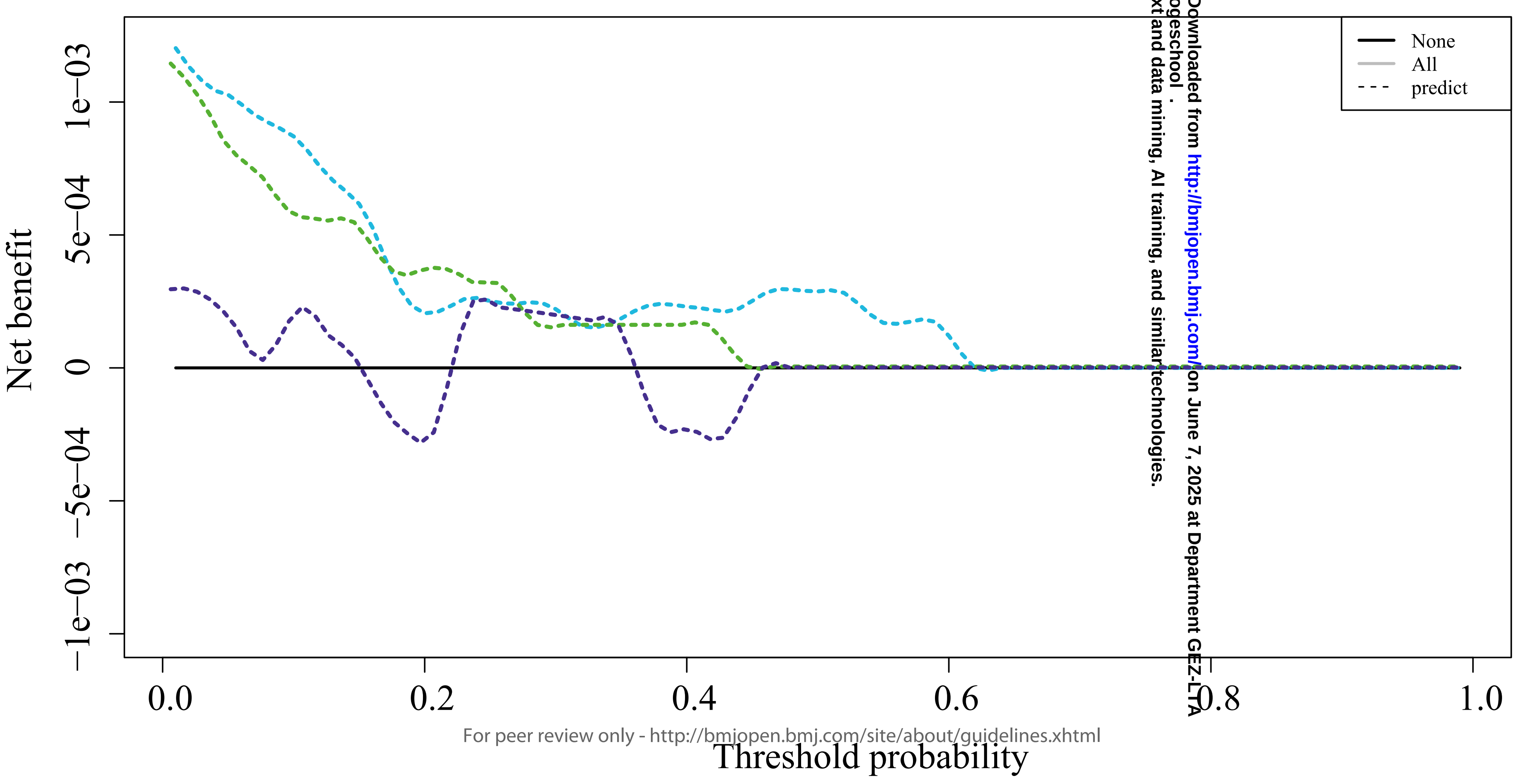
C


None
All
predict
Net benefit
Threshold probability

D


None
All
predict
Net benefit
Threshold probability

E


None
All
predict
Net benefit
Threshold probability

Supplementary table 1 Comparison of Basic Characteristics and Risk Factor Screening between Non-PPH and PPH groups

Characteristics	Non-PPH (N=23,210)		PPH (N=1,623)		χ^2	*P*	Univariate Logistic Regression			Multivariate Logistic Regression		
	Sample size	n%	Sample size	n%			OR	95% CI	*P*	OR	95% CI	*P*
General view												
Age (years)					77.07	***<0.001*****						
<25	1,251	5.39%	58	3.57%			Ref.			Ref.		
25-29	11,047	47.60%	689	42.45%			1.35	1.03, 1.79	***0.034****	1.12	0.85, 1.49	0.430
30-34	8,719	37.57%	726	44.73%			1.80	1.38, 2.39	***<0.001******	1.45	1.11, 1.94	***0.009****
⩾35	2,193	9.45%	150	9.24%			1.48	1.09, 2.03	***0.014****	1.25	0.92, 1.72	0.169
Ethnicity					86.05	***<0.001*****						
Han	20,848	89.82%	1,374	84.66%			Ref.			Ref.		
Manchu	1,693	7.29%	179	11.03%			1.60	1.36, 1.88	***<0.001******	1.[illegible]9	1.34, 1.87	***<0.001******
Other ethnic groups	669	2.88%	70	4.31%			1.59	1.22, 2.03	***<0.001******	1.62	1.24, 2.07	***<0.001******
Educational Attainment					39.46	***<0.001*****	Ref.			Ref.		
High school or below	8,142	35.08%	493	30.38%			1.20	1.08, 1.35	***0.001****	0.95	0.84, 1.07	0.392
Bachelor's degree	12,713	54.77%	926	57.05%			1.43	1.21, 1.69	***<0.001******	1.06	0.88, 1.27	0.520
Postgraduate	2,355	10.15%	204	12.57%								

or higher												
Occupation					359.52	***<0.001****						
Unemployed	10,441	44.98%	932	57.42%			Ref.			Ref.		
Light physical labor	2,573	11.09%	252	15.53%			1.10	0.95, 1.27	0.212	1.07	0.92, 1.24	0.363
Moderate physical labor	9,591	41.32%	420	25.88%			0.49	0.44, 0.55	***<0.001****	0.50	0.44, 0.56	***<0.001****
Heavy physical labor	605	2.61%	19	1.17%			0.35	0.21, 0.54	***<0.001****	0.33	0.20, 0.51	***<0.001****
Family Per Capita Monthly Income (10,000 yuan)					2.98	0.887						
<0.5	9,657	41.61%	668	41.16%			-	-	-	-	-	-
0.5-2.0	8,898	38.34%	636	39.19%			-	-	-	-	-	-
2.0-5.0	3,362	14.49%	222	13.68%			-	-	-	-	-	-
>5.0	1,293	5.57%	97	5.98%			-	-	-	-	-	-
Pre-pregnancy BMI （Kg/m²）					299.11	***<0.001****						
<18.5 （Underweight）	6,869	29.60%	425	26.19%			Ref.			Ref.		
18.5-23.9 （Normal）	14,116	60.82%	889	54.78%			1.02	0.90, 1.15	0.771	1.02	0.90, 1.15	0.803
24.0-27.9 （Overweight）	1,500	6.46%	200	12.32%			2.15	1.80, 2.57	***<0.001****	2.16	1.81, 2.58	***<0.001****

>28.0 (Obesity)	725	3.12%	109	6.72%			2.43	1.93, 3.03	***<0.001*** **	2.43	1.93, 3.04	***<0.001*** **
Smoking					8.56	***0.036*** *						
No	23,128	99.65%	1,612	99.32%			Ref.			Ref.		
Yes	82	0.35%	11	0.68%			1.92	0.97, 3.46	***0.042*** *	[illegible]	0.93, 3.35	0.058
Alcohol Consumption					0.46	0.927						
No	23,153	99.75%	1,620	99.82%			-	-	-	-	-	-
Yes	57	0.25%	3	0.18%			-	-	-	-	-	-
Obstetric and Gynecologic History												
Pregnancy History					46.64	***<0.001*** **						
1	13,914	59.95%	1,071	65.99%			Ref.			Ref.		
2	6,153	26.51%	360	22.18%			0.76	0.67, 0.86	***<0.001*** **	1.01	0.88, 1.15	0.922
⩾3	3,143	13.54%	192	11.83%			0.79	0.68, 0.93	***0.004*** *	1.15	0.96, 1.37	0.118
Parity (number of deliveries)					203.39	***<0.001*** **						
0	19,060	82.12%	1,490	91.81%			Ref.			Ref.		
1	4,027	17.35%	125	7.70%			0.40	0.33, 0.48	***<0.001*** **	0.40	0.32, 0.49	***<0.001*** **
⩾2	123	0.53%	8	0.49%			0.83	0.37, 1.60	0.615	0.68	0.29, 1.39	0.331
history of miscarriage					0.16	0.984						
No	17,078	73.58%	1,189	73.26%			-	-	-	-	-	-
Yes	6,132	26.42%	434	26.74%			-	-	-	-	-	-
spontaneous					0.36	0.947						

abortion												
No	20,874	89.94%	1,465	90.26%			-	-	-	-	-	-
Yes	2,336	10.06%	158	9.74%			-	-	-	-	-	-
induced abortion or medication abortion					1.02	0.797						
No	18,688	80.52%	1,295	79.79%			-	-	-	-	-	-
Yes	4,522	19.48%	328	20.21%			-	-	-	-	-	-
induced labor					26.61	***<0.001*****						
No	22,717	97.88%	1,609	99.14%			Ref.			Ref.		
Yes	493	2.12%	14	0.86%			0.40	0.22, 0.66	***<0.001*****	0.82	0.44, 1.40	0.489
assisted reproductive technology					3.67	0.299						
No	22,595	97.35%	1,589	97.91%			-	-	-	-	-	-
Yes	615	2.65%	34	2.09%			-	-	-	-	-	-
Gestational Age at Delivery (weeks)					241.48	***<0.001*****						
<38	1,441	6.21%	66	4.07%			Ref.			Ref.		
38-40	12,349	53.21%	674	41.53%			1.19	0.93, 1.56	0.184	1.52	1.17, 1.99	***0.002****
>40	9,420	40.59%	883	54.41%			2.05	1.60, 2.67	***<0.001*****	2.92	2.26, 3.84	***<0.001*****
Diabetes					126.81	***<0.001****						

No	20,207	87.06%	1,300	80.10%			Ref.			Ref.		
Yes	3,003	12.94%	323	19.90%			1.67	1.47, 1.90	*<0.001***	1.62	1.42, 1.84	*<0.001***
Hypertension					284.54	*<0.001***						
No	21,649	93.27%	1,385	85.34%			Ref.			Ref.		
Yes	1,561	6.73%	238	14.66%			2.38	2.05, 2.75	*<0.001***	[illegible]	2.30, 3.12	*<0.001***
Anemia					223.87	*<0.001***						
No	19,381	83.50%	1,189	73.26%			Ref.			Ref.		
Yes	3,829	16.50%	434	26.74%			1.85	1.65, 2.07	*<0.001***	[illegible]	1.73, 2.20	*<0.001***
Coagulation disorder					122.64	*<0.001***						
No	23,084	99.46%	1,588	97.84%			Ref.			Ref.		
Yes	126	0.54%	35	2.16%			4.04	2.73, 5.82	*<0.001***	[illegible]	2.60, 5.77	*<0.001***
Uterine fibroids/adenomyosis					249.58	*<0.001***						
No	22,595	97.35%	1,501	92.48%			Ref.			Ref.		
Yes	615	2.65%	122	7.52%			2.99	2.43, 3.64	*<0.001***	[illegible]	2.49, 3.79	*<0.001***
Polyhydramnios					58.05	*<0.001***						
No	20,967	90.34%	1,399	86.20%			Ref.			Ref.		
Yes	2,243	9.66%	224	13.80%			1.50	1.29, 1.73	*<0.001***	[illegible]	1.44, 1.96	*<0.001***
Umbilical cord					0.23	0.973						

entanglement												
No	16,254	70.03%	1,143	70.43%			-	-	-	-	-	-
Yes	6,956	29.97%	480	29.57%			-	-	-	-	-	-
Premature rupture of membranes					336.49	*<0.001***						
No	18,247	78.62%	1,051	64.76%			Ref.			Ref.		
Yes	4,963	21.38%	572	35.24%			2.00	1.80, 2.22	*<0.001***	[illegible]	1.92, 2.41	*<0.001***
Placental abruption					150.97	*<0.001***						
No	23,180	99.87%	1,605	98.89%			Ref.			Ref.		
Yes	30	0.13%	18	1.11%			8.67	4.73, 15.4	*<0.001***	8.19	4.28, 15.30	*<0.001***
Vaginal bleeding during pregnancy					0.73	0.867						
No	22,030	94.92%	1,546	95.26%			-	-	-	-	-	-
Yes	1,180	5.08%	77	4.74%			-	-	-	-	-	-
Scarred uterus					21.53	*<0.001***						
No	22,980	99.01%	1,593	98.15%			Ref.			Ref.		
Yes	230	0.99%	30	1.85%			1.88	1.26, 2.72	*<0.001**	3.05	1.98, 4.53	*<0.001***
Delivery Process and Neonatal Conditions												
Time of delivery					0.13	0.989						
Day shift	9,722	41.89%	685	42.21%			-	-	-	-	-	-

Night shift	13,488	58.11%	938	57.79%			-	-	-	-	-	-
Total duration of labor					633.76	*<0.001***						
normal	22,949	98.88%	1,515	93.35%			Ref.			Ref.		
prolonged	261	1.12%	108	6.65%			6.27	4.96, 7.87	*<0.001***	[illegible]4	1.50, 2.78	*<0.001***
First stage of labor - Latent phase					521.17	*<0.001***						
normal	22,896	98.65%	1,514	93.28%			Ref.			Ref.		
prolonged	314	1.35%	109	6.72%			5.25	4.18, 6.55	*<0.001***	3.[illegible]5	2.44, 4.28	*<0.001***
First stage of labor - Active phase					587.90	*<0.001***						
normal	22,839	98.40%	1,497	92.24%			Ref.			Ref.		
prolonged	371	1.60%	126	7.76%			5.18	4.19, 6.37	*<0.001***	3.[illegible]7	2.47, 4.03	*<0.001***
Second stage of labor					410.58	*<0.001***						
normal	23,077	99.43%	1,561	96.18%			Ref.			Ref.		
prolonged	133	0.57%	62	3.82%			6.89	5.05, 9.31	*<0.001***	4.[illegible]6	3.31, 6.76	*<0.001***
Third stage					349.74	*<0.001**						

of labor						*						
normal	23,065	99.38%	1,563	96.30%			Ref.			Ref.		
prolonged	145	0.62%	60	3.70%			6.11	4.47, 8.24	*<0.001***	4.[illegible]1	3.48, 6.83	*<0.001***
Placental retention/Placenta accreta/Placental implantation					313.75	*<0.001***						
No	19,593	84.42%	1,177	72.52%			Ref.			Ref.		
Yes	3,617	15.58%	446	27.48%			2.05	1.83, 2.30	*<0.001***	2.22	1.96, 2.50	*<0.001***
Analgesia during labor					392.75	*<0.001***						
No	22,440	96.68%	1,458	89.83%			Ref.			Ref.		
Yes	770	3.32%	165	10.17%			3.30	2.76, 3.92	*<0.001***	3.[illegible]2	2.48, 3.66	*<0.001***
Instrumental assistance in delivery					196.11	*<0.001***						
No	22,704	97.82%	1,524	93.90%			Ref.			Ref.		
Yes	506	2.18%	99	6.10%			2.91	2.32, 3.62	*<0.001***	2.[illegible]0	1.79, 2.93	*<0.001***
Lacerations of the cervix, vagina, or perineum					88.25	*<0.001***						
No	21,139	91.08%	1,398	86.14%			Ref.			Ref.		

Yes	2,071	8.92%	225	13.86%			1.64	1.41, 1.90	***<0.001*** **	1.48	1.26, 1.74	***<0.001*** **
Newborn weight (grams)					1510.02	***<0.001*** **						
<2500	221	0.95%	7	0.43%			Ref.			Ref.		
2500-4000	21,944	94.55%	1,281	78.93%			1.84	0.94, 4.34	0.112	[illegible]	0.84, 3.94	0.187
>4000	1,045	4.50%	335	20.64%			10.1	5.09, 24.0	***<0.001*** **	[illegible]	4.68, 22.40	***<0.001*** **
Newborn length (centimeters)					52.57	***<0.001*** **						
≤55	22,566	97.23%	1,542	95.01%			Ref.			Ref.		
>55	644	2.77%	81	4.99%			1.84	1.44, 2.32	***<0.001*** **	[illegible]	0.63, 1.08	0.172

Supplementary table 2 Comparison of Basic Characteristics and Risk Factor Screening between Non-UA-PPH and UA-PPH groups

Characteristics	Non-UA-PPH (N=23,608)		UA-PPH (N=1,225)		χ^2	*P*	Univariate Logistic Regression			Multivariate Logistic Regression		
	Sample size	n%	Sample size	n%			OR	95% CI	*P*	OR	95% CI	*P*
General view												
Age (years)					67.01	***<0.001*****						
<25	1,269	5.38%	40	3.27%			Ref.			Ref.		
25-29	11,212	47.49%	524	42.78%			1.48	1.08, 2.09	***0.018****	1.21	0.88, 1.71	0.266
30-34	8,891	37.66%	554	45.22%			1.98	1.45, 2.78	***<0.001*****	1.55	1.13, 2.19	***0.009****
⩾35	2,236	9.47%	107	8.73%			1.52	1.06, 2.22	***0.027****	1.24	0.86, 1.82	0.259
Ethnicity					39.45	***<0.001*****						
Han	21,172	89.68%	1,050	85.71%			Ref.			Ref.		
Manchu	1,749	7.41%	123	10.04%			1.42	1.16, 1.71	***<0.001*****	1.40	1.15, 1.70	***<0.001*****
Other ethnic groups	687	2.91%	52	4.24%			1.53	1.13, 2.02	***0.004****	1.55	1.15, 2.05	***0.003****
Educational Attainment					54.87	***<0.001*****						
High school or below	8,278	35.06%	357	29.14%			Ref.			Ref.		
Bachelor's degree	12,939	54.81%	700	57.14%			1.25	1.10, 1.43	***<0.001*****	0.99	0.86, 1.13	0.831
Postgraduate	2,391	10.13%	168	13.71%			1.63	1.35, 1.96	***<0.001*****	1.20	0.98, 1.47	0.075

or higher												
Occupation					288.17	***<0.001*** * *						
Unemployed	10,672	45.21%	701	57.22%			Ref.			Ref.		
Light physical labor	2,626	11.12%	199	16.24%			1.15	0.98, 1.36	0.086	[illegible]	0.94, 1.31	0.220
Moderate physical labor	9,701	41.09%	310	25.31%			0.49	0.42, 0.56	***<0.001*** **	[illegible]	0.43, 0.58	***<0.001*** **
Heavy physical labor	609	2.58%	15	1.22%			0.37	0.21, 0.61	***<0.001*** **	[illegible]	0.20, 0.57	***<0.001*** **
Family Per Capita Monthly Income (10,000 yuan)					6.50	0.483						
<0.5	9,824	41.61%	501	40.90%			-	-	-	-	-	-
0.5-2.0	9,052	38.34%	482	39.35%			-	-	-	-	-	-
2.0-5.0	3,421	14.49%	163	13.31%			-	-	-	-	-	-
>5.0	1,311	5.55%	79	6.45%			-	-	-	-	-	-
Pre-pregnancy BMI （Kg/m2）					150.25	***<0.001*** * *						
<18.5（Underweight）	6,949	29.43%	345	28.16%			Ref.			Ref.		
18.5-23.9	14,339	60.74%	666	54.37%			0.94	0.82, 1.07	0.326	0.93	0.82, 1.07	0.313

（Normal）												
24.0-27.9 （Overweight）	1,556	6.59%	144	11.76%			1.86	1.52, 2.28	***<0.001*** **	1.86	1.51, 2.27	***<0.001*** **
>28.0 （Obesity）	764	3.24%	70	5.71%			1.85	1.40, 2.40	***<0.001*** **	1.84	1.39, 2.39	***<0.001*** **
Smoking					2.68	0.444						
No	23,522	99.64%	1,218	99.43%			-	-	-	-	-	-
Yes	86	0.36%	7	0.57%			-	-	-	-	-	-
Alcohol Consumption					0.66	0.883						
No	23,550	99.75%	1,223	99.84%			-	-	-	-	-	-
Yes	58	0.25%	2	0.16%			-	-	-	-	-	-
Obstetric and Gynecologic History												
Pregnancy History					33.29	***<0.001*** **						
1	14,179	60.06%	806	65.80%			Ref.			Ref.		
2	6,244	26.45%	269	21.96%			0.76	0.66, 0.87	***<0.001*** **	0.98	0.84, 1.14	0.830
⩾3	3,185	13.49%	150	12.24%			0.83	0.69, 0.99	***0.039*** *	1.17	0.95, 1.42	0.131
Parity (number of deliveries)					138.11	***<0.001*** **						
0	19,431	82.31%	1,119	91.35%			Ref.			Ref.		
1	4,053	17.17%	99	8.08%			0.42	0.34, 0.52	***<0.001*** **	0.41	0.32, 0.53	***<0.001*** **
⩾2	124	0.53%	7	0.57%			0.98	0.41, 1.95	0.959	0.76	0.31, 1.61	0.513
history of					0.08	0.994						

miscarriage												
No	17,369	73.57%	898	73.31%			-	-	-	-	-	-
Yes	6,239	26.43%	327	26.69%			-	-	-	-	-	-
spontaneous abortion					1.55	0.671						
No	21,228	89.92%	1,111	90.69%			-	-	-	-	-	-
Yes	2,380	10.08%	114	9.31%			-	-	-	-	-	-
induced abortion or medication abortion					2.07	0.559						
No	19,011	80.53%	972	79.35%			-	-	-	-	-	-
Yes	4,597	19.47%	253	20.65%			-	-	-	-	-	-
induced labor					10.41	***0.015****	Ref.			Ref.		
No	23,115	97.91%	1,211	98.86%								
Yes	493	2.09%	14	1.14%			0.54	0.30, 0.89	***0.025****	1.09	0.59, 1.88	0.774
assisted reproductive technology					6.77	0.080						
No	22,981	97.34%	1,203	98.20%			-	-	-	-	-	-
Yes	627	2.66%	22	1.80%			-	-	-	-	-	-
Gestational Age at Delivery (weeks)					189.66	***<0.001**** *						

<38	1,458	6.18%	49	4.00%			Ref.			Ref.		
38-40	12,518	53.02%	505	41.22%			1.20	0.90, 1.64	0.230	1.51	1.12, 2.06	***0.008****
>40	9,632	40.80%	671	54.78%			2.07	1.56, 2.82	***<0.001*****	2.90	2.16, 3.97	***<0.001*****
Diabetes					96.97	***<0.001*****						
No	20,527	86.95%	980	80.00%			Ref.			Ref.		
Yes	3,081	13.05%	245	20.00%			1.67	1.44, 1.92	***<0.001*****	1.60	1.38, 1.86	***<0.001*****
hypertension					256.89	***<0.001*****						
No	21,998	93.18%	1,036	84.57%			Ref.			Ref.		
Yes	1,610	6.82%	189	15.43%			2.49	2.11, 2.93	***<0.001*****	2.77	2.33, 3.28	***<0.001*****
anemia					150.71	***<0.001*****						
No	19,667	83.31%	903	73.71%			Ref.			Ref.		
Yes	3,941	16.69%	322	26.29%			1.78	1.56, 2.03	***<0.001*****	1.89	1.64, 2.16	***<0.001*****
coagulation disorder					0.24	0.972						
No	23,454	99.35%	1,218	99.43%			-	-	-	-	-	-
Yes	154	0.65%	7	0.57%			-	-	-	-	-	-
uterine fibroids/adenomyosis					205.10	***<0.001*****						
No	22,966	97.28%	1,130	92.24%			Ref.			Ref.		
Yes	642	2.72%	95	7.76%			3.01	2.39, 3.74	***<0.001*****	3.04	2.40, 3.82	***<0.001*****
polyhydramnios					50.52	***<0.001*****						

No	21,314	90.28%	1,052	85.88%			Ref.			Ref.		
Yes	2,294	9.72%	173	14.12%			1.53	1.29, 1.80	***<0.001*** **	1.70	1.43, 2.02	***<0.001*** **
umbilical cord entanglement					0.12	0.989						
No	16,535	70.04%	862	70.37%			-	-	-	-	-	-
Yes	7,073	29.96%	363	29.63%			-	-	-	-	-	-
premature rupture of membranes					220.01	***<0.001*** **						
No	18,495	78.34%	803	65.55%			Ref.			Ref.		
Yes	5,113	21.66%	422	34.45%			1.90	1.68, 2.15	***<0.001*** **	2.03	1.79, 2.30	***<0.001*** **
placental abruption					165.43	***<0.001*** **						
No	23,576	99.86%	1,209	98.69%			Ref.			Ref.		
Yes	32	0.14%	16	1.31%			9.75	5.21, 17.5	***<0.001*** **	8.[illegible]8	4.53, 16.70	***<0.001*** **
vaginal bleeding during pregnancy					0.14	0.986						
No	22,411	94.93%	1,165	95.10%			-	-	-	-	-	-
Yes	1,197	5.07%	60	4.90%			-	-	-	-	-	-
scarred uterus					13.95	***0.003*** *						
No	23,370	98.99%	1,203	98.20%			Ref.			Ref.		
Yes	238	1.01%	22	1.80%			1.80	1.12, 2.72	***0.009*** *	2.[illegible]2	1.66, 4.26	***<0.001*** **

Delivery Process and Neonatal Conditions												
Time of delivery					0.29	0.963						
Day shift	9,900	41.93%	507	41.39%			-	-	-	-	-	-
Night shift	13,708	58.07%	718	58.61%			-	-	-	-	-	-
Total duration of labor					433.65	*<0.001***						
normal	23,318	98.77%	1,146	93.55%			Ref.			Ref.		
prolonged	290	1.23%	79	6.45%			5.54	4.27, 7.12	*<0.001***	1.[illegible]1	1.08, 2.11	*0.016**
First stage of labor - Latent phase					548.59	*<0.001***						
normal	23,279	98.61%	1,131	92.33%			Ref.			Ref.		
prolonged	329	1.39%	94	7.67%			5.88	4.62, 7.42	*<0.001***	3.96	2.95, 5.27	*<0.001***
First stage of labor - Active phase					610.26	*<0.001***						
normal	23,219	98.35%	1,117	91.18%			Ref.			Ref.		
prolonged	389	1.65%	108	8.82%			5.77	4.61, 7.18	*<0.001***	3.89	3.01, 4.99	*<0.001***
Second stage of labo					142.00	*<0.001***						

normal	23,448	99.32%	1,190	97.14%			Ref.			Ref.		
prolonged	160	0.68%	35	2.86%			4.31	2.93, 6.16	*<0.001***	2.[illegible]0	1.75, 4.07	*<0.001***
Third stage of labo					34.84	*<0.001***						
normal	23,426	99.23%	1,202	98.12%			Ref.			Ref.		
prolonged	182	0.77%	23	1.88%			2.46	1.55, 3.73	*<0.001***	[illegible]	0.97, 2.52	0.053
Placental retention/Placenta accreta/Placental implantation					234.09	*<0.001***						
No	19,882	84.22%	888	72.49%			Ref.			Ref.		
Yes	3,726	15.78%	337	27.51%			2.03	1.78, 2.30	*<0.001***	2.13	1.86, 2.44	*<0.001***
Analgesia during labor					317.74	*<0.001***						
No	22,801	96.58%	1,097	89.55%			Ref.			Ref.		
Yes	807	3.42%	128	10.45%			3.30	2.70, 4.00	*<0.001***	3.27	2.65, 4.02	*<0.001***
Instrumental assistance in delivery					7.45	0.059						
No	23,043	97.61%	1,185	96.73%			-	-	-	-	-	-
Yes	565	2.39%	40	3.27%			-	-	-	-	-	-
Lacerations					1.08	0.782						

of the cervix, vagina, or perineum												
No	21,418	90.72%	1,119	91.35%			-	-	-	-	-	-
Yes	2,190	9.28%	106	8.65%			-	-	-	-	-	-
Newborn weight (grams)					953.06	***<0.001***[**]						
<2500	225	0.95%	3	0.24%			Ref.			Ref.		
2500-4000	22,241	94.21%	984	80.33%			3.32	1.26, 13.4	***0.039***[*]	3.62	1.14, 12.2	0.058
>4000	1,142	4.84%	238	19.43%			15.6	5.90, 63.5	***<0.001***[**]	14.41	5.40, 58.90	***<0.001***[**]
Newborn length (centimeters)					32.72	***<0.001***[**]						
≤55	22,942	97.18%	1,166	95.18%			Ref.			Ref.		
>55	666	2.82%	59	4.82%			1.74	1.31, 2.27	***<0.001***[**]	0.82	0.60, 1.10	0.193

Supplementary table 3 Comparison of Basic Characteristics and Risk Factor Screening between Non-PF-PPH and PF-PPH groups

Characteristics	Non-PF-PPH (N=24,591)		PF-PPH (N=242)		χ^2	*P*	Univariate Logistic Regression			Multivariate Logistic Regression		
	Sample size	n%	Sample size	n%			OR	95% CI	*P*	OR	95% CI	*P*
General view												
Age (years)				11.46	0.120							
<25	1,297	5.27%	12	4.96%			-	-	-	-	-	-
25-29	11,639	47.33%	97	40.08%			-	-	-	-	-	-
30-34	9,340	37.98%	105	43.39%			-	-	-	-	-	-
⩾35	2,315	9.41%	28	11.57%			-	-	-	-	-	-
Ethnicity					29.18	<0.001**						
Han	22,023	89.56%	199	82.23%			Ref.			Ref.		
Manchu	1,839	7.48%	33	13.64%			1.99	1.35, 2.84	<0.001**	1.94	1.32, 2.78	<0.001**
Other ethnic groups	729	2.96%	10	4.13%			1.52	0.75, 2.73	0.201	1.55	0.76, 2.78	0.181
Educational Attainment					3.44	0.632						
High school or below	8,559	34.81%	76	31.40%			-	-	-	-	-	-
Bachelor's degree	13,496	54.88%	143	59.09%			-	-	-	-	-	-
Postgraduate or higher	2,536	10.31%	23	9.50%			-	-	-	-	-	-

Occupation					77.00	***<0.001***						
Unemployed	11,218	45.62%	155	64.05%			Ref.			Ref.		
Light physical labor	2,796	11.37%	29	11.98%			0.75	0.49, 1.10	0.159	0.74	0.49, 1.08	0.137
Moderate physical labor	9,955	40.48%	56	23.14%			0.41	0.30, 0.55	***<0.001***	0.41	0.30, 0.55	***<0.001***
Heavy physical labor	622	2.53%	2	0.83%			0.23	0.04, 0.73	***0.041****	0.23	0.04, 0.71	***0.038****
Family Per Capita Monthly Income (10,000 yuan)					2.01	0.959						
<0.5	10,222	41.57%	103	42.56%			-	-	-	-	-	-
0.5-2.0	9,440	38.39%	94	38.84%			-	-	-	-	-	-
2.0-5.0	3,549	14.43%	35	14.46%			-	-	-	-	-	-
>5.0	1,380	5.61%	10	4.13%			-	-	-	-	-	-
Pre-pregnancy BMI （Kg/m2）					64.09	***<0.001***						
<18.5 （Underweight）	7,235	29.42%	59	24.38%			Ref.			Ref.		
18.5-23.9 （Normal）	14,873	60.48%	132	54.55%			1.09	0.80, 1.49	0.590	1.09	0.81, 1.50	0.578

24.0-27.9（Overweight）	1,667	6.78%	33	13.64%			2.43	1.56, 3.70	*<0.001***	2.45	1.58, 3.75	*<0.001***
>28.0（Obesity）	816	3.32%	18	7.44%			2.71	1.54, 4.51	*<0.001***	2.72	1.55, 4.55	*<0.001***
Smoking					2.68	0.444						
No	24,500	99.63%	240	99.17%			-	-	-	-	-	-
Yes	91	0.37%	2	0.83%			-	-	-	-	-	-
Alcohol Consumption					0.60	0.897	-	-	-	-	-	-
No	24,532	99.76%	241	99.59%								
Yes	59	0.24%	1	0.41%								
Obstetric and Gynecologic History												
Pregnancy History					14.33	*<0.001***						
1	14,822	60.27%	163	67.36%			Ref.			Ref.		
2	6,454	26.25%	59	24.38%			0.83	0.61, 1.11	0.226	1.11	0.80, 1.51	0.519
⩾3	3,315	13.48%	20	8.26%			0.55	0.33, 0.85	*0.012**	0.80	0.47, 1.28	0.369
Parity (number of deliveries)					39.16	*<0.001***						
0	20,324	82.65%	226	93.39%			Ref.			Ref.		
1	4,137	16.82%	15	6.20%			0.33	0.18, 0.53	*<0.001***	0.36	0.20, 0.63	*<0.001***
⩾2	130	0.53%	1	0.41%			0.69	0.04, 3.11	0.714	0.42	0.05, 4.55	0.933
history of miscarriage					0.17	0.982						

No	18,087	73.55%	180	74.38%			-	-	-	-	-	-
Yes	6,504	26.45%	62	25.62%			-	-	-	-	-	-
spontaneous abortion					0.04	0.998						
No	22,122	89.96%	217	89.67%			-	-	-	-	-	-
Yes	2,469	10.04%	25	10.33%			-	-	-	-	-	-
induced abortion or medication abortion					0.27	0.965						
No	19,786	80.46%	197	81.40%			-	-	-	-	-	-
Yes	4,805	19.54%	45	18.60%			-	-	-	-	-	-
induced labor					6.48	0.090						
No	24,085	97.94%	241	99.59%			-	-	-	-	-	-
Yes	506	2.06%	1	0.41%			-	-	-	-	-	-
assisted reproductive technology					2.34	0.504						
No	23,951	97.40%	233	96.28%			-	-	-	-	-	-
Yes	640	2.60%	9	3.72%			-	-	-	-	-	-
Gestational Age at Delivery (weeks)					26.69	<0.001**						
<38	1,499	6.10%	8	3.31%			Ref.			Ref.		

38-40	12,916	52.52%	107	44.21%			1.55	0.81, 3.47	0.231	1.[illegible]9	0.98, 4.24	0.085
>40	10,176	41.38%	127	52.48%			2.34	1.22, 5.21	***0.020****	3.[illegible]0	1.60, 6.97	***0.002****
Diabetes					30.50	***<0.001*****						
No	21,318	86.69%	189	78.10%			Ref.			Ref.		
Yes	3,273	13.31%	53	21.90%			1.83	1.33, 2.46	***<0.001*****	[illegible]6	1.28, 2.38	***<0.001*****
hypertension					26.00	***<0.001*****						
No	22,824	92.81%	210	86.78%			Ref.			Ref.		
Yes	1,767	7.19%	32	13.22%			1.97	1.33, 2.82	***<0.001*****	2.[illegible]2	1.43, 3.06	***<0.001*****
anemia					29.60	***<0.001*****						
No	20,392	82.92%	178	73.55%			Ref.			Ref.		
Yes	4,199	17.08%	64	26.45%			1.75	1.30, 2.31	***<0.001*****	1.[illegible]9	1.33, 2.39	***<0.001*****
coagulation disorder					0.24	0.971						
No	24,432	99.35%	240	99.17%			-	-	-	-	-	-
Yes	159	0.65%	2	0.83%			-	-	-	-	-	-
uterine fibroids/adenomyosis					27.94	***<0.001*****						
No	23,871	97.07%	225	92.98%			Ref.			Ref.		
Yes	720	2.93%	17	7.02%			2.50	1.47, 4.00	***<0.001*****	2.[illegible]4	1.42, 3.92	***<0.001*****
polyhydramnios					9.25	***0.026****						
No	22,158	90.11%	208	85.95%			Ref.			Ref.		

Yes	2,433	9.89%	34	14.05%			1.49	1.02, 2.11	***0.033****	1.60	1.09, 2.29	***0.013****
umbilical cord entanglement					0.09	0.993						
No	17,229	70.06%	168	69.42%			-	-	-	-	-	-
Yes	7,362	29.94%	74	30.58%			-	-	-	-	-	-
premature rupture of membranes					46.49	***<0.001*****						
No	19,141	77.84%	157	64.88%			Ref.			Ref.		
Yes	5,450	22.16%	85	35.12%			1.90	1.45, 2.47	***<0.001*****	1.96	1.49, 2.57	***<0.001*****
placental abruption					1.23	0.747						
No	24,544	99.81%	241	99.59%			-	-	-	-	-	-
Yes	47	0.19%	1	0.41%			-	-	-	-	-	-
vaginal bleeding during pregnancy					0.88	0.831						
No	23,344	94.93%	232	95.87%			-	-	-	-	-	-
Yes	1,247	5.07%	10	4.13%			-	-	-	-	-	-
scarred uterus					4.90	0.179						
No	24,336	98.96%	237	97.93%			-	-	-	-	-	-
Yes	255	1.04%	5	2.07%			-	-	-	-	-	-
Delivery Process and Neonatal Conditions												

Time of delivery					3.84	0.279						
Day shift	10,295	41.86%	112	46.28%			-	-	-	-	-	-
Night shift	14,296	58.14%	130	53.72%			-	-	-	-	-	-
Total duration of labor					61.71	***<0.001*****						
normal	24,236	98.56%	228	94.21%			Ref.			Ref.		
prolonged	355	1.44%	14	5.79%			4.19	2.31, 7.00	***<0.001*****	3.06	1.49, 5.88	***0.001****
First stage of labor - Latent phase					11.86	***0.008****						
normal	24,177	98.32%	233	96.28%			Ref.			Ref.		
prolonged	414	1.68%	9	3.72%			2.26	1.07, 4.16	***0.018****	1.14	0.48, 2.41	0.749
First stage of labor - Active phase					0.57	0.903						
normal	24,100	98.00%	236	97.52%			-	-	-	-	-	-
prolonged	491	2.00%	6	2.48%			-	-	-	-	-	-
Second stage of labo					54.00	***<0.001*****						
normal	24,405	99.24%	233	96.28%			Ref.			Ref.		

prolonged	186	0.76%	9	3.72%			5.07	2.38, 9.45	***<0.001****	3.30	1.54, 7.05	***0.001****
Third stage of labo					1178.60	***<0.001*****						
normal	24,422	99.31%	206	85.12%			Ref.			Ref.		
prolonged	169	0.69%	36	14.88%			25.31	17.03, 36.72	***<0.001*****	27.00	17.51, 40.72	***<0.001*****
Placental retention/Placenta accreta/Placental implantation					33.41	***<0.001*****						
No	20,591	83.73%	179	73.97%			Ref.			Ref.		
Yes	4,000	16.27%	63	26.03%			1.81	1.35, 2.40	***<0.001*****	1.93	1.43, 2.58	***<0.001*****
Analgesia during labor					18.20	***<0.001*****						
No	23,674	96.27%	224	92.56%			Ref.			Ref.		
Yes	917	3.73%	18	7.44%			2.07	1.23, 3.27	***0.003****	0.94	0.52, 1.60	0.835
Instrumental assistance in delivery					3.38	0.336						
No	23,995	97.58%	233	96.28%			-	-	-	-	-	-
Yes	596	2.42%	9	3.72%			-	-	-	-	-	-
Lacerations of the cervix,					7.40	0.060						

vagina, or perineum												
No	22,326	90.79%	211	87.19%			-	-	-	-	-	-
Yes	2,265	9.21%	31	12.81%			-	-	-	-	-	-
Newborn weight (grams)					212.47	***<0.001****						
<2500	226	0.92%	2	0.83%			Ref.			Ref.		
2500-4000	23,035	93.67%	190	78.51%			0.93	0.30, 5.65	0.922	[illegible]	0.27, 5.39	0.860
>4000	1,330	5.41%	50	20.66%			4.25	1.31, 26.1	***0.046****	[illegible]	1.21, 24.90	0.059
Newborn length (centimeters)					1.10	0.777						
⩽55	23,875	97.09%	233	96.28%			-	-	-	-	-	-
>55	716	2.91%	9	3.72%			-	-	-	-	-	-

Supplementary table 4 Comparison of Basic Characteristics and Risk Factor Screening between Non-CT-PPH and CT-PPH groups

Characteristics	Non-CT-PPH (N=24,694)		CT-PPH (N=139)		χ^2	*P*	Univariate Logistic Regression			Multivariate Logistic Regression		
	Sample size	n%	Sample size	n%			OR	95% CI	*P*	OR	95% CI	*P*
General view												
Age (years)					11.23	0.129						
<25	1,303	5.28%	6	4.32%			-	-	-	-	-	-
25-29	11,682	47.31%	54	38.85%			-	-	-	-	-	-
30-34	9,379	37.98%	66	47.48%			-	-	-	-	-	-
⩾35	2,330	9.44%	13	9.35%			-	-	-	-	-	-
Ethnicity					24.67	***<0.001***						
Han	22,109	89.53%	113	81.29%			Ref.			Ref.		
Manchu	1,856	7.52%	16	11.51%			1.69	0.96, 2.77	0.051	1.67	0.95, 2.75	0.057
Other ethnic groups	729	2.95%	10	7.19%			2.68	1.31, 4.89	***0.003****	2.71	1.32, 4.95	***0.003****
Educational Attainment					4.25	0.515						
High school or below	8,585	34.77%	50	35.97%			-	-	-	-	-	-
Bachelor's degree	13,569	54.95%	70	50.36%			-	-	-	-	-	-
Postgraduate or higher	2,540	10.29%	19	13.67%			-	-	-	-	-	-

Occupation					10.34	0.170						
Unemployed	11,307	45.79%	66	47.48%			-	-	-	-	-	-
Light physical labor	2,802	11.35%	23	16.55%			-	-	-	-	-	-
Moderate physical labor	9,963	40.35%	48	34.53%			-	-	-	-	-	-
Heavy physical labor	622	2.52%	2	1.44%			-	-	-	-	-	-
Family Per Capita Monthly Income (10,000 yuan)					4.07	0.772						
<0.5	10,261	41.55%	64	46.04%			-	-	-	-	-	-
0.5-2.0	9,481	38.39%	53	38.13%			-	-	-	-	-	-
2.0-5.0	3,569	14.45%	15	10.79%			-	-	-	-	-	-
>5.0	1,383	5.60%	7	5.04%			-	-	-	-	-	-
Pre-pregnancy BMI （Kg/m2）					270.37	***<0.001*** **						
<18.5 （Underweight）	7,274	29.46%	20	14.39%			Ref.			Ref.		
18.5-23.9 （Normal）	14,939	60.50%	66	47.48%			1.61	0.99, 2.72	0.064	1.[illegible]0	0.99, 2.72	0.064
24.0-27.9	1,671	6.77%	29	20.86%			6.31	3.58, 11.30	***<0.001*** **	6.[illegible]3	3.59, 11.40	***<0.001*** **

（Overweight ）												
>28.0 （Obesity）	810	3.28%	24	17.27%			10.80	5.93, 19.82	***<0.001*** **	10.70	5.91, 19.71	***<0.001*** **
Smoking					1.05	0.789						
No	24,601	99.62%	139	100.00 %			-	-	-	-	-	-
Yes	93	0.38%	0	0.00%			-	-	-	-	-	-
Alcohol Consumption					0.68	0.879						
No	24,634	99.76%	139	100.00 %			-	-	-	-	-	-
Yes	60	0.24%	0	0.00%			-	-	-	-	-	-
Obstetric and Gynecologic History												
Pregnancy History					8.22	0.145						
1	14,892	60.31%	93	66.91%			-	-	-	-	-	-
2	6,487	26.27%	26	18.71%			-	-	-	-	-	-
⩾3	3,315	13.42%	20	14.39%			-	-	-	-	-	-
Parity (number of deliveries)					18.31	***0.003*** *						
0	20,422	82.70%	128	92.09%			Ref.			Ref.		
1	4,142	16.77%	10	7.19%			0.39	0.19, 0.70	***0.004*** *	0.40	0.20, 0.73	***0.006*** *
⩾2	130	0.53%	1	0.72%			1.23	0.07, 5.54	0.839	1.25	0.07, 5.70	0.824
history of					0.38	0.945						

miscarriage												
No	18,167	73.57%	100	71.94%			-	-	-	-	-	-
Yes	6,527	26.43%	39	28.06%			-	-	-	-	-	-
spontaneous abortion					0.67	0.881						
No	22,216	89.97%	123	88.49%			-	-	-	-	-	-
Yes	2,478	10.03%	16	11.51%			-	-	-	-	-	-
induced abortion or medication abortion					0.07	0.996						
No	19,872	80.47%	111	79.86%			-	-	-	-	-	-
Yes	4,822	19.53%	28	20.14%			-	-	-	-	-	-
induced labor					0.51	0.917						
No	24,189	97.95%	137	98.56%			-	-	-	-	-	-
Yes	505	2.05%	2	1.44%			-	-	-	-	-	-
assisted reproductive technology					1.52	0.679						
No	24,047	97.38%	137	98.56%			-	-	-	-	-	-
Yes	647	2.62%	2	1.44%			-	-	-	-	-	-
Gestational Age at Delivery (weeks)					22.32	***<0.001**** *						

<38	1,501	6.08%	6	4.32%			Ref.			Ref.		
38-40	12,967	52.51%	56	40.29%			1.08	0.50, 2.81	0.857	-	-	-
>40	10,226	41.41%	77	55.40%			1.88	0.89, 4.86	0.136	-	-	-
Diabetes					10.98	***0.012****						
No	21,396	86.64%	111	79.86%			Ref.			Ref.		
Yes	3,298	13.36%	28	20.14%			1.64	1.06, 2.44	***0.020****	[illegible]3	0.99, 2.29	***0.045****
hypertension					10.34	***0.016****						
No	22,912	92.78%	122	87.77%			Ref.			Ref.		
Yes	1,782	7.22%	17	12.23%			1.79	1.04, 2.90	***0.025****	[illegible]3	1.06, 2.97	***0.021****
anemia					23.32	***<0.001*****						
No	20,470	82.89%	100	71.94%			Ref.			Ref.		
Yes	4,224	17.11%	39	28.06%			1.89	1.29, 2.72	***<0.001*****	1.[illegible]8	1.28, 2.71	***<0.001*****
coagulation disorder					0.02	0.999						
No	24,534	99.35%	138	99.28%			-	-	-	-	-	-
Yes	160	0.65%	1	0.72%			-	-	-	-	-	-
uterine fibroids/adenomyosis					17.34	***<0.001*****						
No	23,967	97.06%	129	92.81%			Ref.			Ref.		
Yes	727	2.94%	10	7.19%			2.56	1.25, 4.64	***0.005****	2.[illegible]4	1.19, 4.43	***0.007****
polyhydramnios					6.20	0.102						
No	22,247	90.09%	119	85.61%			-	-	-	-	-	-
Yes	2,447	9.91%	20	14.39%			-	-	-	-	-	-

umbilical cord entanglement					4.01	0.261						
No	17,292	70.03%	105	75.54%			-	-	-	-	-	-
Yes	7,402	29.97%	34	24.46%			-	-	-	-	-	-
premature rupture of membranes					24.20	***<0.001*** **						
No	19,207	77.78%	91	65.47%			Ref.			Ref.		
Yes	5,487	22.22%	48	34.53%			1.85	1.29, 2.61	***<0.001*** **	1.70	1.19, 2.41	***0.003*** *
placental abruption					4.01	0.260						
No	24,647	99.81%	138	99.28%			-	-	-	-	-	-
Yes	47	0.19%	1	0.72%			-	-	-	-	-	-
vaginal bleeding during pregnancy					0.28	0.964						
No	23,445	94.94%	131	94.24%			-	-	-	-	-	-
Yes	1,249	5.06%	8	5.76%			-	-	-	-	-	-
scarred uterus					0.41	0.937						
No	24,436	98.96%	137	98.56%			-	-	-	-	-	-
Yes	258	1.04%	2	1.44%			-	-	-	-	-	-
Delivery Process and Neonatal Conditions												
Time of					0.30	0.960						

delivery												
Day shift	10,351	41.92%	56	40.29%			-	-	-	-	-	-
Night shift	14,343	58.08%	83	59.71%			-	-	-	-	-	-
Total duration of labor					97.56	***<0.001****						
normal	24,337	98.55%	127	91.37%			Ref.			Ref.		
prolonged	357	1.45%	12	8.63%			6.44	3.35, 11.3	***<0.001****	2.[illegible]9	0.99, 7.48	***0.045****
First stage of labor - Latent phase					18.54	***<0.001****						
normal	24,278	98.32%	132	94.96%			Ref.			Ref.		
prolonged	416	1.68%	7	5.04%			3.09	1.30, 6.18	***0.004****	1.42	0.46, 3.75	0.514
First stage of labor - Active phase					77.03	***<0.001****						
normal	24,210	98.04%	126	90.65%			Ref.			Ref.		
prolonged	484	1.96%	13	9.35%			5.16	2.76, 8.85	***<0.001****	1.66	0.65, 3.87	0.266
Second stage of labo					974.69	***<0.001****						
normal	24,523	99.31%	115	82.73%			Ref.			Ref.		
prolonge	171	0.69%	24	17.27%			29.9	18.42, 46.90	***<0.001****	36.04	17.40, 72.31	***<0.001****

d												
Third stage of labo					41.62	***<0.001***						
normal	24,495	99.19%	133	95.68%			Ref.			Ref.		
prolonged	199	0.81%	6	4.32%			5.55	2.16, 11.7	***<0.001***	[illegible]	1.43, 15.11	***0.005***
Placental retention/Placenta accreta/Placental implantation					31.49	***<0.001***						
No	20,671	83.71%	99	71.22%			Ref.			Ref.		
Yes	4,023	16.29%	40	28.78%			2.08	1.42, 2.98	***<0.001***	2.[illegible]8	1.48, 3.77	***<0.001***
Analgesia during labor					46.29	***<0.001***						
No	23,775	96.28%	123	88.49%			Ref.			Ref.		
Yes	919	3.72%	16	11.51%			3.37	1.92, 5.52	***<0.001***	2.[illegible]2	1.03, 4.46	***0.032***
Instrumental assistance in delivery					2311.00	***<0.001***						
No	24,154	97.81%	74	53.24%			Ref.			Ref.		
Yes	540	2.19%	65	46.76%			39.31	27.80, 55.41	***<0.001***	27.[illegible]1	17.80, 43.22	***<0.001***
Lacerations of the cervix, vagina, or					1561.20	***<0.001***						

perineum												
No	22,506	91.14%	31	22.30%			Ref.			Ref.		
Yes	2,188	8.86%	108	77.70%			35.82	24.3, 54.4	***<0.001*****	37.42	23.80, 61.01	***<0.001*****
Newborn weight (grams)					669.48	***<0.001*****						
<2500	227	0.92%	1	0.72%			Ref.			Ref.		
2500-4000	23,144	93.72%	81	58.27%			0.79	0.18, 14.0	0.820	[illegible]	0.12, 12.3	0.689
>4000	1,323	5.36%	57	41.01%			9.78	2.14, 173	***0.024****	[illegible]	1.15, 120	0.089
Newborn length (centimeters)					18.02	***<0.001*****						
≤55	23,979	97.10%	129	92.81%			Ref.			Ref.		
>55	715	2.90%	10	7.19%			2.60	1.27, 4.72	***0.004****	[illegible]	0.47, 2.50	0.762

Supplementary table 5 Comparison of Basic Characteristics and Risk Factor Screening between Non-CA-PPH and CA-PPH groups

Characteristics	Non-CA-PPH (N=24,757)		CA-PPH (N=76)		χ^2	*P*	Univariate Logistic Regression			Multivariate Logistic Regression		
	Sample size	n%	Sample size	n%			OR	95% CI	*P*	OR	95% CI	*P*
General view												
Age (years)					6.09	0.530						
<25	1,308	5.28%	1	1.32%			-	-	-	-	-	-
25-29	11,702	47.27%	34	44.74%			-	-	-	-	-	-
30-34	9,412	38.02%	33	43.42%			-	-	-	-	-	-
⩾35	2,335	9.43%	8	10.53%			-	-	-	-	-	-
Ethnicity					6.92	0.227						
Han	22,158	89.50%	64	84.21%			-	-	-	-	-	-
Manchu	1,862	7.52%	10	13.16%			-	-	-	-	-	-
Other ethnic groups	737	2.98%	2	2.63%			-	-	-	-	-	-
Educational Attainment					1.65	0.895						
High school or below	8,611	34.78%	24	31.58%			-	-	-	-	-	-
Bachelor's degree	13,597	54.92%	42	55.26%			-	-	-	-	-	-
Postgraduate or higher	2,549	10.30%	10	13.16%			-	-	-	-	-	-
Occupation					21.85	***0.003****						

Unemployed	11,330	45.76%	43	56.58%			Ref.			Ref.		
Light physical labor	2,811	11.35%	14	18.42%			1.31	0.69, 2.34	0.378	1.29	0.68, 2.30	0.411
Moderate physical labor	9,993	40.36%	18	23.68%			0.47	0.27, 0.81	***0.008****	0.48	0.27, 0.81	***0.008****
Heavy physical labor	623	2.52%	1	1.32%			0.42	0.02, 1.94	0.395	0.42	0.02, 1.93	0.393
Family Per Capita Monthly Income (10,000 yuan)					6.42	0.492						
<0.5	10,297	41.59%	28	36.84%			-	-	-	-	-	-
0.5-2.0	9,503	38.39%	31	40.79%			-	-	-	-	-	-
2.0-5.0	3,569	14.42%	15	19.74%			-	-	-	-	-	-
>5.0	1,388	5.61%	2	2.63%			-	-	-	-	-	-
Pre-pregnancy BMI （Kg/m2）					15.86	***0.026****						
<18.5 （Underweight）	7,282	29.41%	12	15.79%			Ref.			Ref.		
18.5-23.9 （Normal）	14,953	60.40%	52	68.42%			2.11	1.17, 4.15	***0.020****	2.09	1.16, 4.11	***0.021****
24.0-27.9 （Overweight	1,692	6.83%	8	10.53%			2.87	1.12, 6.95	***0.021****	2.88	1.12, 6.97	***0.021****

)												
>28.0 (Obesity)	830	3.35%	4	5.26%			2.92	0.82, 8.42	0.064	2.93	0.82, 8.43	0.064
Smoking					20.82	***<0.001***						
No	24,666	99.63%	74	97.37%			Ref.			Ref.		
Yes	91	0.37%	2	2.63%			7.33	1.19, 23.81	***0.006****	[illegible]	1.08, 21.70	***0.009****
Alcohol Consumption					0.37	0.947						
No	24,697	99.76%	76	100.00%			-	-	-	-	-	-
Yes	60	0.24%	0	0.00%			-	-	-	-	-	-
Obstetric and Gynecologic History												
Pregnancy History					7.08	0.215						
1	14,932	60.31%	53	69.74%			-	-	-	-	-	-
2	6,500	26.26%	13	17.11%			-	-	-	-	-	-
⩾3	3,325	13.43%	10	13.16%			-	-	-	-	-	-
Parity (number of deliveries)					15.86	***0.007****						
0	20,479	82.72%	71	93.42%			Ref.			Ref.		
1	4,148	16.75%	4	5.26%			0.28	0.08, 0.67	***0.013****	0.27	0.08, 0.68	***0.014****
⩾2	130	0.53%	1	1.32%			2.22	0.13, 10.1	0.431	2.56	0.14, 13.3	0.375
history of miscarriage					0.16	0.983						

No	18,210	73.55%	57	75.00%			-	-	-	-	-	-
Yes	6,547	26.45%	19	25.00%			-	-	-	-	-	-
spontaneous abortion					0.04	0.998						
No	22,271	89.96%	68	89.47%			-	-	-	-	-	-
Yes	2,486	10.04%	8	10.53%			-	-	-	-	-	-
induced abortion or medication abortion					0.57	0.903						
No	19,920	80.46%	63	82.89%			-	-	-	-	-	-
Yes	4,837	19.54%	13	17.11%			-	-	-	-	-	-
induced labor					3.18	0.365						
No	24,250	97.95%	76	100.00 %			-	-	-	-	-	-
Yes	507	2.05%	0	0.00%			-	-	-	-	-	-
assisted reproductive technology					0.02	0.999						
No	24,110	97.39%	74	97.37%			-	-	-	-	-	-
Yes	647	2.61%	2	2.63%			-	-	-	-	-	-
Gestational Age at Delivery (weeks)					14.46	***0.013****						

<38	1,503	6.07%	4	5.26%			Ref.			Ref.		
38-40	12,994	52.49%	29	38.16%			0.84	0.33, 2.83	0.742	-	-	-
>40	10,260	41.44%	43	56.58%			1.57	0.64, 5.24	0.386	-	-	-
Diabetes					0.75	0.860						
No	21,443	86.61%	64	84.21%			-	-	-	-	-	-
Yes	3,314	13.39%	12	15.79%			-	-	-	-	-	-
hypertension					2.44	0.486						
No	22,966	92.77%	68	89.47%			-	-	-	-	-	-
Yes	1,791	7.23%	8	10.53%			-	-	-	-	-	-
anemia					18.39	***<0.001*** **						
No	20,517	82.87%	53	69.74%			Ref.			Ref.		
Yes	4,240	17.13%	23	30.26%			2.10	1.26, 3.38	***0.003****	1.93	1.13, 3.20	***0.012****
coagulation disorder					3100.80	***<0.001*** **						
No	24,624	99.46%	48	63.16%			Ref.			Ref.		
Yes	133	0.54%	28	36.84%			108.01	65.10, 176.01	***<0.001*****	114.21	67.90, 190.00	***<0.001*****
uterine fibroids/adenomyosis					0.51	0.917						
No	24,023	97.04%	73	96.05%			-	-	-	-	-	-
Yes	734	2.96%	3	3.95%			-	-	-	-	-	-
polyhydramnios					0.62	0.892						
No	22,299	90.07%	67	88.16%			-	-	-	-	-	-

Yes	2,458	9.93%	9	11.84%			-	-	-	-	-	-
umbilical cord entanglement					0.39	0.943						
No	17,342	70.05%	55	72.37%			-	-	-	-	-	-
Yes	7,415	29.95%	21	27.63%			-	-	-	-	-	-
premature rupture of membranes					39.31	<0.001**						
No	19,255	77.78%	43	56.58%			Ref.			Ref.		
Yes	5,502	22.22%	33	43.42%			2.69	1.69, 4.22	<0.001**	2.79	1.72, 4.51	<0.001**
placental abruption					9.96	0.019*						
No	24,710	99.81%	75	98.68%			Ref.			Ref.		
Yes	47	0.19%	1	1.32%			7.01	0.39, 32.7	0.056	-	-	-
vaginal bleeding during pregnancy					0.39	0.942						
No	23,503	94.93%	73	96.05%			-	-	-	-	-	-
Yes	1,254	5.07%	3	3.95%			-	-	-	-	-	-
scarred uterus					12.38	0.006*						
No	24,500	98.96%	73	96.05%			Ref.			Ref.		
Yes	257	1.04%	3	3.95%			3.92	0.96, 10.6	0.021*	6.[illegible]9	1.48, 21.10	0.004*
Delivery Process and Neonatal Conditions												

Time of delivery					0.14	0.986						
Day shift	10,374	41.90%	33	43.42%			-	-	-	-	-	-
Night shift	14,383	58.10%	43	56.58%			-	-	-	-	-	-
Total duration of labor					62.15	*<0.001***						
normal	24,395	98.54%	69	90.79%			Ref.			Ref.		
prolonged	362	1.46%	7	9.21%			6.84	2.84, 14.0	*<0.001***	5.57	2.18, 12.10	*<0.001***
First stage of labor - Latent phase					4.59	0.205						
normal	24,337	98.30%	73	96.05%			-	-	-	-	-	-
prolonged	420	1.70%	3	3.95%			-	-	-	-	-	-
First stage of labor - Active phase					8.27	0.041						
normal	24,264	98.01%	72	94.74%			-	-	-	-	-	-
prolonged	493	1.99%	4	5.26%			-	-	-	-	-	-
Second stage of labo					19.57	*<0.001***						
normal	24,565	99.22%	73	96.05%			Ref.			Ref.		

prolonged	192	0.78%	3	3.95%			5.26	1.28, 14.3	***0.005****	3.13	0.71, 9.65	0.078
Third stage of labo					0.45	0.930						
normal	24,553	99.18%	75	98.68%			-	-	-	-	-	-
prolonged	204	0.82%	1	1.32%			-	-	-	-	-	-
Placental retention/Placenta accreta/Placental implantation					40.92	*<0.001***						
No	20,721	83.70%	49	64.47%			Ref.			Ref.		
Yes	4,036	16.30%	27	35.53%			2.83	1.74, 4.49	*<0.001***	2.97	1.83, 4.73	*<0.001***
Analgesia during labor					27.45	*<0.001***						
No	23,831	96.26%	67	88.16%			Ref.			Ref.		
Yes	926	3.74%	9	11.84%			3.46	1.60, 6.59	*<0.001***	3.54	1.64, 6.79	*<0.001***
Instrumental assistance in delivery					0.81	0.848						
No	24,153	97.56%	75	98.68%			-	-	-	-	-	-
Yes	604	2.44%	1	1.32%			-	-	-	-	-	-
Lacerations of the cervix,					0.01	0.999						

vagina, or perineum												
No	22,468	90.75%	69	90.79%			-	-	-	-	-	-
Yes	2,289	9.25%	7	9.21%			-	-	-	-	-	-
Newborn weight (grams)					11.83	***0.037****						
<2500	227	0.92%	1	1.32%			Ref.			Ref.		
2500-4000	23,159	93.55%	66	86.84%			0.65	0.14, 11.4	0.666	-	-	
>4000	1,371	5.54%	9	11.84%			1.49	0.28, 27.5	0.706	-	-	-
Newborn length (centimeters)					2.95	0.399						
⩽55	24,036	97.09%	72	94.74%			-	-	-	-	-	-
>55	721	2.91%	4	5.26%			-	-	-	-	-	-

BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-089734.R2
Article Type:	Original research
Date Submitted by the Author:	02-Dec-2024
Complete List of Authors:	Li, Jinke; Shengjing Hospital of China Medical University, Department of Obstetrics and Gynecology Zhang, Dandan; Shengjing Hospital of China Medical University, Department of Obstetrics and Gynecology Lin, Hong; Liaoning Maternal and Child Health Hospital, Department of Obstetrics and Gynecology Shao, Mengyuan; Shenyang Women's and Children's Hospital, Department of Obstetrics and Gynecology Wang, Xiaoxue; Shengjing Hospital of China Medical University, Department of Health Management Chen, Xueting; Shengjing Hospital of China Medical University, Department of Health Management Zhou, Yangzi; Shengjing Hospital of China Medical University, Department of Obstetrics and Gynecology Song, Zixuan; Shengjing Hospital of China Medical University, Department of Obstetrics and Gynecology
Primary Subject Heading:	Obstetrics and gynaecology
Secondary Subject Heading:	Obstetrics and gynaecology
Keywords:	Maternal medicine < OBSTETRICS, PERINATOLOGY, Postpartum Women < Postpartum Period, PREVENTIVE MEDICINE

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Postpartum Hemorrhage Following Vaginal Delivery: A Comprehensive Analysis and Development of Predictive Models for Etiological Subgroups in Chinese Women

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Abstract:

Objectives: This study aimed to dissect the etiological subgroups of postpartum hemorrhage (PPH) that occur after vaginal delivery in women with full-term singleton pregnancies. Our goal was to craft and validate predictive models to guide clinical decision-making and optimize resource allocation.

Design: A retrospective cohort study.

Setting: Shengjing Hospital of China Medical University, Liaoning Maternal and Child Health Hospital, and Shenyang Women's and Children's Hospital.

Participants: 29,842 women who underwent vaginal delivery were enrolled in the study across three hospitals from 2016 to 2022.

Primary outcome measures: PPH, categorized into uterine atony (UA), placental factors (PF), cervical trauma (CT), and coagulation abnormalities (CA) by etiology.

Results: The logistic regression for overall PPH and UA-PPH showcased high discrimination (AUCs of 0.807 and 0.794, respectively), coupled with commendable calibration and DCA-assessed clinical utility, culminating in the development of a nomogram for risk prediction. The PF-PPH model exhibited a modest AUC of 0.739, while the CT-PPH and CA-PPH models demonstrated suboptimal clinical utility and calibration.

Conclusions: The study identified factors associated with PPH and developed models with good performance for overall PPH and UA-PPH. The nomogram offers a valuable tool for risk prediction. However, models for PF-PPH, CT-PPH, and CA-PPH require further refinement. Future research should focus on larger samples and multi-center validation for enhanced model generalizability.

Keywords: Postpartum Hemorrhage, Vaginal Delivery, Etiological Subgroups, Predictive Models, nomogram

Strengths and limitations of this study

- This study included data from large multicenter cohorts in China, comprising 29,842 women to enhance the statistical power of the analysis.
- Predictive models were developed for postpartum hemorrhage following vaginal delivery and for different etiological subgroups.

- The predictive models were visualized using nomograms for clinical application.
- This study's test set is a single-center study specifically focused on vaginal delivery PPH, with a limited number of positive samples.
- The existing external validation datasets are from hospitals of the same region and level, resulting in a lack of diversification and generalizability.

Background

Postpartum hemorrhage (PPH) is defined as blood loss exceeding 500 milliliters within 24 hours following vaginal delivery or exceeding 1,000 milliliters within 24 hours following cesarean delivery.[1] PPH is a widespread and serious medical condition that poses significant risks to women's health around the world. It is particularly devastating in developing countries, where it is a principal contributor to maternal mortality.[2] It is estimated that approximately 1.4 million maternal deaths globally are tied to PPH each year, with the tragic loss of a woman's life to this condition occurring every four minutes.[3 4]. In Australia, the incidence of PPH increased from 6.3% in 2000 to 8.0% in 2009. [5] Similarly, in the United States, the rate of PPH rose from 2.7% in 1999 to 3.2% in 2014. [6] In China, despite a relatively lower maternal mortality rate of 17.8 per 100,000 in 2019, PPH accounted for one-quarter of these deaths.[7]

The World Health Organization (WHO) has conducted an analysis revealing that while PPH is a significant factor in maternal mortality and morbidity, the mortality rates vary considerably across different regions.[8] In high-income countries, the risk of death due to PPH is significantly lower than in low-income countries.[9] In high-income nations, the substantial blood loss primarily caused by PPH accounts for 13.4% of overall maternal mortality, while in Africa and Asia, this figure stands at 34% and 30.8%, respectively. [8] The international obstetric community is actively engaged in research to better understand the incidence, risk factors, and management strategies for PPH.[10-12]. Despite the establishment of global clinical guidelines and the identification of various risk factors, further exploration is needed to enhance our understanding and management of PPH.[13 14].

PPH can be etiologically classified into uterine atony (UA), placental factors (PF), cervical trauma (CT), and coagulation abnormalities (CA), each requiring distinct clinical management and treatment strategies. [15] Clear etiological classification is crucial for developing preventive strategies, formulating management plans, and rational allocation of medical resources.[16] While numerous cohort studies have focused on identifying risk factors for PPH, there is a scarcity of studies that quantify and weigh these risk factors for a comprehensive PPH risk assessment.[17 18] Given the complexity of PPH and the interplay of multiple risk factors, a holistic approach is necessary to accurately assess the risk of PPH.

Clinical prediction models (CPMs) have been widely applied in clinical settings in recent years. By constructing CPMs, physicians and patients can make better medical decisions, and health departments at all levels can allocate medical resources more rationally. These models play an irreplaceable role in primary prevention (assessing the quantitative risk of future diseases) and secondary prevention (constructing highly sensitive and specific diagnostic schemes, practicing "early detection, early diagnosis, early treatment"), reflecting significant health economic value.

There is a gap in research regarding the development of clinical prediction models for women specifically following vaginal delivery. Many studies are constrained by limited sample sizes, which can affect the robustness of the models[19]. Other research has focused on PPH prediction models for women undergoing cesarean sections.[20] Our study aims to address this gap by constructing a clinical prediction model tailored to PPH after vaginal delivery. By analyzing clinical data and risk factors through logistic regression, we can determine the relative impact of each factor on the likelihood of PPH. We further refine our model by performing secondary fitting based on the four etiological subgroups, creating a nomogram that enhances the precision of predicting high-risk populations for PPH. This work provides essential insights for the prevention and management of this critical condition.

Materials and methods

Data Sources and Ethics Statement

This cohort study was conducted at the obstetric wards of Shengjing Hospital of China Medical University, Liaoning Maternal and Child Health Hospital, and Shenyang Women's and Children's Hospital. The study population comprised women who underwent vaginal delivery between January 1, 2016, and December 31, 2022. The outcomes of interest were fetal birth outcomes within the first 24 hours postpartum. Inclusion criteria were women who consented to participate after being informed of the study's scope. Exclusion criteria were defined as follows: age under 18 or over 50 years, delivery occurring at less than 37 weeks or more than 42 weeks of gestation, multiple births, and instances of induced labor, stillbirth, or fetal death. These factors were excluded to focus on women with full-term, singleton pregnancies undergoing vaginal delivery. Preterm and postterm pregnancies, multiple pregnancies, and induced labor are associated with different physiological characteristics and obstetric risks, which could confound the analysis of PPH risk in this cohort. Additionally, stillbirth and fetal death involve other pathological processes and significant complications that are outside the scope of this study's focus on live births and PPH risk.

Comprehensive data encompassing maternal characteristics, obstetric and gynecologic history, pregnancy complications, and details of the delivery process and neonatal conditions were collected (Supplement 1). To protect participant privacy, all data were anonymized. The study protocol was approved by the Ethical Review Committee of Shengjing Hospital of China Medical University (No. 2016PS344K), and written information about the study was provided to all participants.

Sample Size Calculation

According to the obstetric big data from Shengjing Hospital of China Medical University, the incidence of PPH is approximately 6%-7%. Based on the sample size estimation using the psamplesize package in R software, the minimum sample size required for constructing clinical prediction models is estimated to be between 1,048 and 1,536. The sample size included in this study far exceeds the minimum requirement.

Covariates

A range of covariates were taken into account, including:(1) Age, categorized as <25, 25-29, 30-34, and ≥35 years; (2) Ethnicity, divided into Han, Manchu, and other; (3) Education level, classified as high school or below, bachelor's degree, and postgraduate or above; (4) Occupation, categorized as unemployed, light physical labor, moderate physical labor, and heavy physical labor (based on the International Physical Activity Questionnaire, IPAQ); (5) Monthly household income per capita, divided into <0.5, 0.5-2.0, 2.0-5.0, and >5.0 thousand yuan; (6) Pre-pregnancy BMI, categorized as underweight (<18.5 kg/m^2), normal (18.5-23.9 kg/m^2), overweight (24-27.9 kg/m^2), and obese (≥28 kg/m^2); (7) Smoking and alcohol consumption history; (8) Gravidity, categorized as 1, 2, or ≥3 times; (9) Parity, divided into 0, 1, or ≥2 times; (10) History of miscarriage and induced labor; (11) Assisted reproductive technology; (11) Gestational age, categorized as <38, 38-40, and >40 weeks; (12) Pregnancy complications: diabetes, hypertension, anemia, coagulation disorder, uterine fibroids/adenomyosis, polyhydramnios, umbilical cord entanglement, premature rupture of membranes, placental abruption, vaginal bleeding during pregnancy, and scarred uterus; (13) Delivery time, divided into daytime (8-16), evening (17-23), and night (0-7) shifts; (14) Total duration of labor, categorized as normal (≤24 hours) and prolonged (>24 hours); (15) Latent phase of the first stage, categorized as normal (primiparous ≤20 hours, multiparous ≤14 hours) and prolonged (primiparous >20 hours, multiparous >14 hours); (16) Active phase of the first stage, categorized as normal (≤8 hours) and prolonged (>8 hours); (17) Second stage duration, categorized as normal and prolonged based on specific criteria for primiparous and multiparous women with or without analgesia; (18) Third stage duration, categorized as normal (≤30 minutes) and prolonged (>30 minutes); (19) Placental retention/placenta accreta/placental implantation; (20) Analgesia during labor; (21)

Instrumental assistance in delivery; (22) Lacerations of the cervix, vagina, or perineum; (23) Newborn weight and length.

Etiology Subgroups

In this study, PPH was defined according to WHO standards as blood loss exceeding 500 milliliters following vaginal delivery. Patients were categorized into those with and without PPH based on this definition, and further analysis was conducted on the underlying etiologies, including UA, PF, CT, and CA.

Model Construction

For the purpose of our investigation, we have categorized the participants from the Shengjing hospital of China Medical University as Cohort I. This cohort was systematically split into a training dataset and an internal validation dataset with a ratio of 7:3. The training dataset was instrumental in developing the predictive model, while the internal validation dataset served to assess the model's predictive accuracy. An additional cohort, comprising participants from two other hospitals, was designated as Cohort II. This external dataset was used to validate the model's general applicability and its efficacy in real-world clinical scenarios.

Within the confines of the datasets, we employed both univariate and multivariate logistic regression analyses to identify potential risk factors across various subgroups. These factors were then subjected to a rigorous selection process for inclusion in the predictive model. The selected factors were further analyzed using multivariate logistic regression (Bidirectional elimination) in training dataset to discern their discriminative power, thereby establishing them as predictive indicators for the model. The women in the training set were divided into PPH and non-PPH groups based on PPH as the outcome variable. Subsequently, they were further categorized by etiology into UA-PPH and non-UA-PPH groups, PF-PPH and non-PF-PPH groups, CT-PPH and non-CT-PPH groups, and CA-PPH and non-CA-PPH groups. Five predictive models were constructed sequentially, and the performance of these models was corroborated using both the test and validation datasets to ascertain the most accurate predictive model.

Evaluating the Performance of the Models

The area under the receiver operating characteristic curve (AUC) was the primary metric used to evaluate the discrimination of our models. An AUC value above 0.75 suggests excellent model discrimination, while an AUC below 0.6 indicates poor discrimination. Calibration curves were used to assess the models' accuracy, with closer alignment between observed and predicted incidence rates indicating higher model fidelity. Decision Curve Analysis (DCA) was also employed to evaluate the clinical utility of the models, offering a thorough assessment of the models' net benefits across various clinical scenarios.

Nomogram Development

Nomograms for postpartum hemorrhage and its four etiological subgroups were crafted to offer a visual representation of the risk scores derived from the logistic regression analysis. This tool simplifies the interpretation of complex statistical outcomes, providing a more straightforward approach to understanding risk assessments.

Statistical Analysis

All statistical computations, construction of traditional logistic models, and calculations of model discrimination and calibration were carried out using R version 3.6.3 from the R Foundation for Statistical Computing, Vienna, Austria. This software facilitated the development of traditional logistic predictive models and their subsequent evaluation for discriminative power, calibration, and clinical utility. Continuous variables conforming to the normal distribution were expressed as the mean ± standard deviation (SD), while non-normally distributed continuous variables were presented as medians with interquartile ranges. Categorical data were analyzed using chi-square tests, and continuous variables were analyzed using ANOVA or Mann-Whitney tests, as appropriate. Variables were adjusted as dummy variables, and odds ratios (OR) with corresponding 95% confidence intervals (95% CI) were calculated using univariate and multivariate logistic regression analyses, with significance level set at $P < 0.05$.

Patient and public involvement

Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Results

From 2016 to 2022, a total of 27,389 patients underwent vaginal delivery at the Shengjing Hospital of China Medical University. Forty-two patients under 18 years of age or over 50 years old were excluded. Additionally, 2,456 patients with gestational age less than 37 weeks or more than 42 weeks at delivery, 6 patients with multiple births, and 52 patients with induced labor, stillbirth, or fetal death were also excluded. Ultimately, 24,833 patients met the inclusion criteria and were enrolled in the cohort. According to the inclusion and exclusion criteria, a total of 5,099 patients in cohort II were included in the external validation dataset. The general characteristics of all patients are presented in Table 1. All patients were followed up within 24 hours after delivery for neonatal outcomes, with a follow-up rate of 100%. The patient selection criteria flowchart is shown in Figure 1.

Comparison of Basic Characteristics and Risk Analysis for Postpartum Hemorrhage (PPH) and Its Subgroups

Based on the occurrence of postpartum hemorrhage, the parturients in cohort one were divided into two groups: the non-PPH group and the PPH group. Similarly, within the etiological subgroups, they were categorized into UA-PPH and non-UA-PPH groups, PF-PPH and non-PF-PPH groups, CT-PPH and non-CT-PPH groups, and CA-PPH and non-CA-PPH groups. The comparison of basic characteristics and analysis of risk factors for each group are presented in Supplementary Tables 1-5.

In the multivariate analysis of risk factors, apart from age, parity, pre-pregnancy BMI, anemia, premature rupture of membranes, and combined placenta retention/placenta accreta/placental implantation, other specific risk factors were found to be associated with specific etiologies of postpartum hemorrhage. For instance, polyhydramnios was associated with UA-PPH; analgesia during labor, instrumental assistance, and cervical/vaginal/perineal lacerations were associated with the occurrence of CT-PPH (Table 2).

Selection of Predictive Factors for PPH and Its Subgroups in the Training Dataset

Through random sampling of cohort one, 70% of the data (N=17,383) from parturients were used to form the training dataset, with the remaining approximately 30% (N=7,450) forming the internal validation dataset. Multivariate analysis of risk factors for PPH and its subgroups was performed again in the training dataset, with results presented in Supplemental Table 1. After selection, predictive models were constructed for each group using the selected risk factors.

Evaluation of Predictive Model Discrimination

The ROC curves were plotted using R software for the PPH group and its various subgroups across the training dataset, internal and external validation dataset.

The results indicated that the predictive models, namely PPH-Logistic, UA-PPH-Logistic, PF-PPH-Logistic, CT-PPH-Logistic, and CA-PPH-Logistic, demonstrated high discriminative power in the training dataset with AUCs of 0.807 (95% CI: 0.792-0.821), 0.794 (95% CI: 0.777-0.811), 0.796 (95% CI: 0.761-0.830), 0.935 (95% CI: 0.901-0.969), and 0.802 (95% CI: 0.769-0.892), respectively.(Figure 2A-E) However, the PF-PPH-Logistic model exhibited only moderate discrimination with an AUC of 0.739 (95% CI: 0.666-0.813) in the internal validation dataset. Furthermore, the CA-PPH-Logistic model showed significantly lower discrimination in the external validation dataset with an AUC of 0.662 (95% CI: 0.450-0.873), which was notably inferior to its performance in the training and test datasets. This discrepancy may be attributed to the lower proportion of patients with coagulation disorders causing PPH in the validation dataset.

Assessment of Predictive Model Calibration

Calibration curves for the PPH and its subgroups were plotted for the Logistic predictive model within the training dataset (Supplemental Figure 1A-E). The performance of the PF-PPH-Logistic, particularly the CT-PPH-Logistic, and CA-PPH-Logistic models was suboptimal in certain aspects, with lower calibration, as observed in the test and external validation datasets (Supplemental Figure 1 F-J, Supplemental Figure 1K-O).

Evaluation of Clinical Utility of Predictive Models

In the evaluation of clinical utility, the PPH-Logistic and UA-PPH-Logistic models demonstrated satisfactory performance across all datasets. However, the clinical utility of the PF-PPH-Logistic, CT-PPH-Logistic, and CA-PPH-Logistic models was found to be relatively poor. (Supplemental Figure 2A-O)

Nomogram Construction

Using R software, we constructed nomograms for PPH and UA-PPH, with the results presented in Figure 3A-B. Physicians can assess the risk probability of PPH occurrence by summing the individual scores on the nomogram. This practical tool aids in a more precise estimation of PPH risk, thereby enhancing clinical decision-making.

Discussion

Maternal mortality has emerged as a pivotal indicator in global maternal and child health, serving as a significant benchmark for assessing the socioeconomic status of nations. Consequently, the effective reduction, prevention, and improvement of conditions leading to maternal deaths have become a focal point for public health initiatives worldwide. Among the various causes of maternal mortality, PPH stands out as a preventable condition that has attracted considerable attention. [17 18] With the rise in global economic standards and the evolution of medical technologies, there has been an approximate 50% decrease in the worldwide maternal mortality rate between 1990 and 2015. In China, the maternal mortality rate has seen a dramatic reduction of 98.78%[21] since the establishment of the People's Republic of China. Despite these advancements, a substantial proportion of maternal deaths, estimated between 27% and 40%[22], remain avoidable due to a range of factors, including inadequate social and medical interventions. PPH is a critical area of focus within this context, and the prediction and prevention of PPH to reduce avoidable maternal mortality present a significant challenge on the global stage.

Early prediction or identification of PPH and timely preventive or intervention measures are extremely valuable, necessitating a clear understanding of the etiologies of PPH for targeted management. The overall PPH model provides a comprehensive perspective that captures common risk factors for postpartum hemorrhage, offering a baseline risk assessment for women. This broad assessment helps in formulating general preventive measures and policies, ensuring that all women at risk of PPH are monitored. Although the overall PPH model demonstrates higher overall accuracy, it may mask the heterogeneity between different PPH subtypes in clinical practice, limiting its guidance for individualized management. Subtype-specific models, on the other hand, can delve deeper into the specific risk factors of each subtype, helping to enhance our understanding of the potential mechanisms of PPH and meet the diverse needs of clinical practice. The value provided by these models in treatment is more critical, as they can guide clinicians to adopt effective therapeutic strategies tailored to the specific etiology, thereby reducing complications and mortality and promoting the development of precision medicine. In this study, the predictive models developed for PPH and UA-PPH demonstrated excellent performance in effectively identifying high-risk populations. For women at high risk for UA-PPH, early cord clamping should be considered. After the placenta is delivered, uterine fundal massage can be performed, and oxytocin should be administered immediately to promote uterine contraction and reduce bleeding. If necessary, mechanical compression or uterine artery ligation can be employed for hemostasis. In other PPH subtype models, the performance may be suboptimal due to factors such as insufficient positive sample sizes, requiring further sample expansion and model optimization to enhance predictive ability and improve the general applicability of the models. Overall, high-risk women for PPH should be closely monitored, and proactive interventions should be implemented, such as promoting uterine contractions, advising patients to avoid excessive straining that could cause lacerations, and timely correction of coagulopathy.

The advent of the big data era has brought new opportunities for the management of PPH. The era is characterized by the digitization and standardization of medical records, along with an increasing volume of data, which has ushered in an era of data-driven management and treatment for maternal care. Leveraging big data analytics for disease risk prediction can contribute to the reduction of avoidable maternal deaths.

A review of the literature reveals over 200 prognostic models in obstetrics, three of which are pertinent to PPH.[23] However, few models have been applied in routine clinical practice, and the majority of studies have not provided model formulas, hindering independent external validation. The earliest PPH prediction model, dating back to 1994, originated from a case-control study in Zimbabwe[24], where PPH was defined as blood loss exceeding 600 milliliters following an unassisted vaginal delivery. This study included 150 PPH patients and 299 patients with normal deliveries, with a low positive predictive value of less than 7% and only 35.0% of patients experiencing postpartum bleeding. Since then, approximately ten additional PPH prediction models have been published. These models have varied in focus, with some concentrating on the relationship between placenta previa and PPH, while others have included only vaginal deliveries[24-27] or cesarean sections[20 28 29], and some have targeted women with placental implantation disorders[30] or general obstetric populations[31]. PPH research has been conducted in hospitals across various countries, including Italy, China, France, the United States, the United Kingdom, South Korea, the Netherlands, Spain, Zimbabwe, Denmark, and Egypt. From the 14 published studies, a total of 124 independent variables were identified as potential predictors (ranging from 5 to 38 per study), and 64 variables were ultimately selected for the final models (an average of 5-15 factors per study). Common predictors included parity, low pre-pregnancy hemoglobin, antenatal bleeding, maternal age over 35, gestational age, high neonatal weight, multiple pregnancies, body mass index (BMI) over 25, previous cesarean section, anterior placenta, and retained placenta. These predictors have also been incorporated into our predictive model.

Once a clinical prediction model is developed, it must undergo validation and evaluation to assess the model's effectiveness, reproducibility, and portability. Published PPH prediction models have reported AUCs ranging from 0.70[25] to 0.90[27], with external validation AUCs of 0.83[20], which are comparable to the results of our study. In addition to discrimination, calibration is essential to evaluate the consistency between the predicted probabilities of clinical outcomes and the observed event probabilities. Only a few studies, such as one by Albright in 2019 on the prediction of PPH following cesarean section, have utilized calibration curves[32], while most have employed the Hosmer-Lemeshow goodness-of-fit test to compare predicted probabilities with actual event probabilities for significant differences. The Hosmer-Lemeshow test, however, has limited efficacy in small-sample prediction models as it does not quantify model calibration[33 34]or provide direction or magnitude of mis calibration[35].

The Decision Curve Analysis (DCA)[35] has been used to evaluate the clinical utility of models, focusing on the selection of true positives from positive patients to avoid unnecessary medical resource consumption and reduce harm from overtreatment of false positives. DCA is particularly suited for scenarios where symptoms suggest the possibility of disease but a diagnosis has not yet been confirmed, guiding the decision on whether or what kind of screening method to adopt for disease diagnosis. The DCA's axes represent the threshold probability (P) and net benefit (NB), allowing for the determination of intervention measures based on the predicted probability of adverse events.[36]

In essence, both ROC and DCA can be used to assess the quality of predictive models, but they differ fundamentally in their theoretical constructs. While ROC combines sensitivity and specificity to compare the accuracy of predictive models through the AUC, the highest AUC does not necessarily represent the optimal model in clinical practice. For instance, in this study, patients in the CA-PPH group, due to coagulation disorders, all underwent cesarean section deliveries to minimize the number of false positives. This requires decision-makers to consider practical issues, as a high ROC does not always indicate the best treatment approach. Furthermore, for some extreme cases, the accuracy of ROC becomes less critical, and DCA evaluation results are needed for reference.

Statistical analysis of previously published PPH data has shown that factors such as general anesthesia in pregnant women, prolonged use of oxytocin, excessive uterine tension (multiple pregnancies, polyhydramnios), and chorioamnionitis are all associated with uterine atony, potentially increasing the risk of postpartum bleeding. Previous studies have suggested that for pregnant women with high-risk factors, assessing and selecting appropriate treatment options and management based on the type and weight of different risks can reduce the risk of adverse pregnancy outcomes or death[37]. Early prediction and intervention are key measures in reducing maternal mortality, with studies finding that timely interventions can effectively lower maternal mortality rates by 10%[38]. Establishing a model that predicts the risk of PPH following vaginal delivery and guides clinical practice is a significant task for maternal and child health.

Limitation

Although some subtypes in this study showed promising predictive results, the clinical application of the logistic regression models for the PF-PPH, CT-PPH, and CA-PPH groups is limited by insufficient positive sample sizes in these subgroups, which prevents fully achieving the initial goal of etiology-based PPH prediction. Compared to previously published models, this study's test set is a single-center study focusing specifically on vaginal delivery PPH, with a limited number of positive samples. Additionally, the external validation datasets come from hospitals of the same region and level, lacking diversity and generalizability. Therefore, future plans include multi-center collaboration, increasing sample sizes, and seeking higher-quality prediction methods to provide more robust clinical evidence.

Furthermore, the PPH scoring model developed in this study is not applicable to women with preterm or postterm labor, induced labor, or multiple pregnancies. These populations have unique physiological and pathological factors, along with higher complication rates, that fall outside the scope of this study. Further research is needed to develop individualized risk assessment models for these groups. It is important to note that these models incorporate not only antepartum factors but also postpartum factors such as labor characteristics and newborn weight. This comprehensive approach aids in understanding the mechanisms of PPH and provides a basis for targeted prevention or intervention strategies aimed at risk factors. However, these models are not entirely suitable for antepartum clinical decision-making or real-time prediction.

Conclusion

In conclusion, our study has successfully developed and validated predictive models for PPH following vaginal delivery, offering a novel approach to risk assessment in this critical area of maternal health. The models, particularly for overall PPH and UA-PPH, demonstrated high discriminative power and clinical utility, with the nomogram providing a user-friendly tool for clinicians. Despite the promising results, limitations exist in the application of the PF-PPH, CT-PPH, and CA-PPH models due to the insufficient positive sample size in these subgroups. The generalizability of our findings may also be limited by the single-center nature of the study and the regional characteristics of the included hospitals. Future research should aim to expand the sample size and include multi-center data to improve the models' applicability and robustness. This study contributes to the growing body of evidence on PPH management and has the potential to influence policy and practice, ultimately enhancing maternal care and outcomes.

List of abbreviations

RP: Refined Peyton;
TTM: Traditional Teaching-mode
DOPS: direct observation of procedural skills
OB-GYN: Obstetrics and Gynecology
CBVI: computer-based video instruction
PEARLS: Promoting Excellence and Reflective Learning in Simulation
OSCE: objective structured clinical assessment

Declarations

Ethics approval and consent to participate

Ethics approval and consent to participate: The study was approved by the Ethics Committee of Shengjing Hospital of China Medical University (No. 2016PS344K, Date.17/12/2016). All participants provided informed consent.

Consent for publication

Not Applicable

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Competing interests

No potential conflict of interest was reported by the author(s).

Funding

This study was supported in part by grants from 345 Talent Project of Shengjing Hospital of China Medical University (No. M0946), and Medical Education Research Project of Liaoning Province (No. 2022-N005-03).

Authors' contributions

Contributors JL and DZ contributed equally to this study. JL, DZ and KZ designed the study and drafted the manuscript. HL, MS, and XW done the data collection. YZ and XC designed the statistical analysis plan. DZ has participated the training and reviewed and co-authored the manuscript with ZS. All authors have read and approved this manuscript. ZS is responsible for the overall content as guarantor.

Acknowledgements

We would like to express our gratitude to all those who helped us during the writing of this manuscript. Thanks to all the peer reviewers for their opinions and suggestions. We would like to acknowledge that Jinke Li and Dandan Zhang have contributed equally to this work.

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Table 1 The general view of the maternal.

Characteristics	Cohort population (N=24,833)	Validation population (N=5009)	P
Age (years) *，N（%）			0.393
<25	1,309 （5.27%）	266 (5.31%)	
25-29	11,736 （47.26%）	2340 (46.71%)	
30-34	9,445 （38.03%）	1959 (39.11%)	
⩾35	2,343 （9.44%）	444 (8.86%)	
Ethnicity，N（%）			0.983
Han	22,222 （89.49%）	4,475 (89%)	
Manchu	1,872 （7.54%）	389 (7.8%)	
Other ethnic groups	739 （2.98%）	145 (2.9%)	
Educational Attainment，N（%）			0.115
High school or below	8,635 （34.77%）	1,742 (35%)	
Bachelor's degree	13,639 （54.92%）	2,703 (54%)	
Postgraduate or higher	2,559 （10.30%）	564 (11%)	
Occupation，N（%）			0.777
Unemployed	11,373 （45.80%）	2,266 (45%)	
Light physical labor	2,825 （11.38%）	569 (11%)	
Moderate physical labor	10,011 （40.31%）	2,038 (41%)	
Heavy physical labor	624 （2.51%）	136 (2.7%)	
Family Per Capita Monthly Income (10,000 yuan)，N（%）			0.9862
<0.5	10,325 （41.58%）	2,080 (42%)	
0.5-2.0	9,534 （38.39%）	1,922 (38%)	
2.0-5.0	3,584 （14.43%）	720 (14%)	
>5.0	1,390 （5.60%）	287 (5.7%)	
Pre-pregnancy BMI （Kg/m2） *，N（%）			<0.001
<18.5（Underweight）	7,294 （29.37%）	1475 (29.45%)	
18.5-23.9（Normal）	15,005 （60.42%）	2963 (59.16%)	
24.0-27.9（Overweight）	1,700 （6.85%）	307 (6.13%)	
>28.0（Obesity）	834 （3.36%）	264 (5.29%)	
Pregnancy History，N（%）			0.565
1	14,985 （60.34%）	3,005 (60%)	
2	6,513 （26.23%）	1,303 (26%)	
⩾3	3,335 （13.43%）	701 (14%)	
Parity (number of deliveries)，N（%）			0.775
0	20,550 （82.75%）	4,127 (82%)	
1	4,152 （16.72%）	853 (17%)	
⩾2	131 （0.53%）	29 (0.6%)	
Gestational Age at Delivery (weeks)，N（%）			0.434

<38	1,507 （6.07%）	296 （5.91%）	
38-40	13,023 （52.44%）	2589 （51.59%）	
>40	10,303 （41.49%）	2129 （42.50%）	
Blood Loss（ml）	393.54±92.53	413.48±124.65	0.081
Postpartum Hemorrhage，N（%）	1,623 （6.54%）	286 （5.71%）	0.032
Due to uterine atony，N（%）	1,225 （4.93%）	266 （5.31%）	0.279
Due to placental factors，N（%）	242 （0.97%）	43 （0.86%）	0.489
Due to Cancal Trauma，N（%）	139 （0.56%）	31 （0.62%）	0.686
Due to coagulation disorders，N（%）	76 （0.31%）	17 （0.34%）	0.705

Table 2: Multivariate Risk Factor Analysis for Postpartum Hemorrhage (PPH) within Subgroups

Characteristics	PPH	UA-PPH	PF-PPH	CT-PPH	CA-PPH
		General view			
Age (years)	*	*	-	-	-
Ethnicity	**	**	**	*	-
Educational Attainment	-	-	-	-	-
Occupation	**	**	**	-	*
Family Per Capita Monthly Income (10,000 yuan)	-	-	-	-	-
Pre-pregnancy BMI （Kg/m2）	**	**	**	**	*
Smoking	-	-	-	-	*
Alcohol Consumption	-	-	-	-	-
		Obstetric and Gynecologic History			
Pregnancy History	-	-	-	-	-
Parity (number of deliveries)	**	**	**	*	*
History of miscarriage	-	-	-	-	-
Spontaneous abortion	-	-	-	-	-
Induced abortion or medication abortion	-	-	-	-	-
Induced labor	-	-	-	-	-
Assisted reproductive technology	-	-	-	-	-
Gestational Age at Delivery (weeks)	**	**	*	-	-
Diabetes	**	**	**	*	-
Hypertension	**	**	**	*	-
Anemia	**	**	**	**	*

Coagulation disorder	**	-	-	-	*
Uterine fibroids/adenomyosis	**	**	**	*	-
Polyhydramnios	**	**	*	-	-
Umbilical cord entanglement	-	-	-	-	-
Premature rupture of membranes	**	**	**	*	**
Placental abruption	**	**	-	-	-
Vaginal bleeding during pregnancy	-	-	-	-	-
Scarred uterus	**	**	-	-	*
		Delivery Process and Neonatal Conditions			
Time of delivery	-	-	-	-	-
Total duration of labor	**	*	*	*	**
First stage of labor - Latent phase	**	**	-	-	-
First stage of labor - Active phase	**	**	-	-	-
Second stage of labor	**	**	*	**	-
Third stage of labor	**	-	**	*	-
Placental retention/Placenta accreta/Placental implantation	**	**	**	**	**
Analgesia during labor	**	**	-	*	**
Instrumental assistance in delivery	**	-	-	**	-
Lacerations of the cervix, vagina, or perineum	**	-	-		-
Newborn weight (grams)	**	**	-	-	-
Newborn length (centimeters)	-	-	-	-	-

*: $P<0.05$; **: $P<0.001$

Figure legend

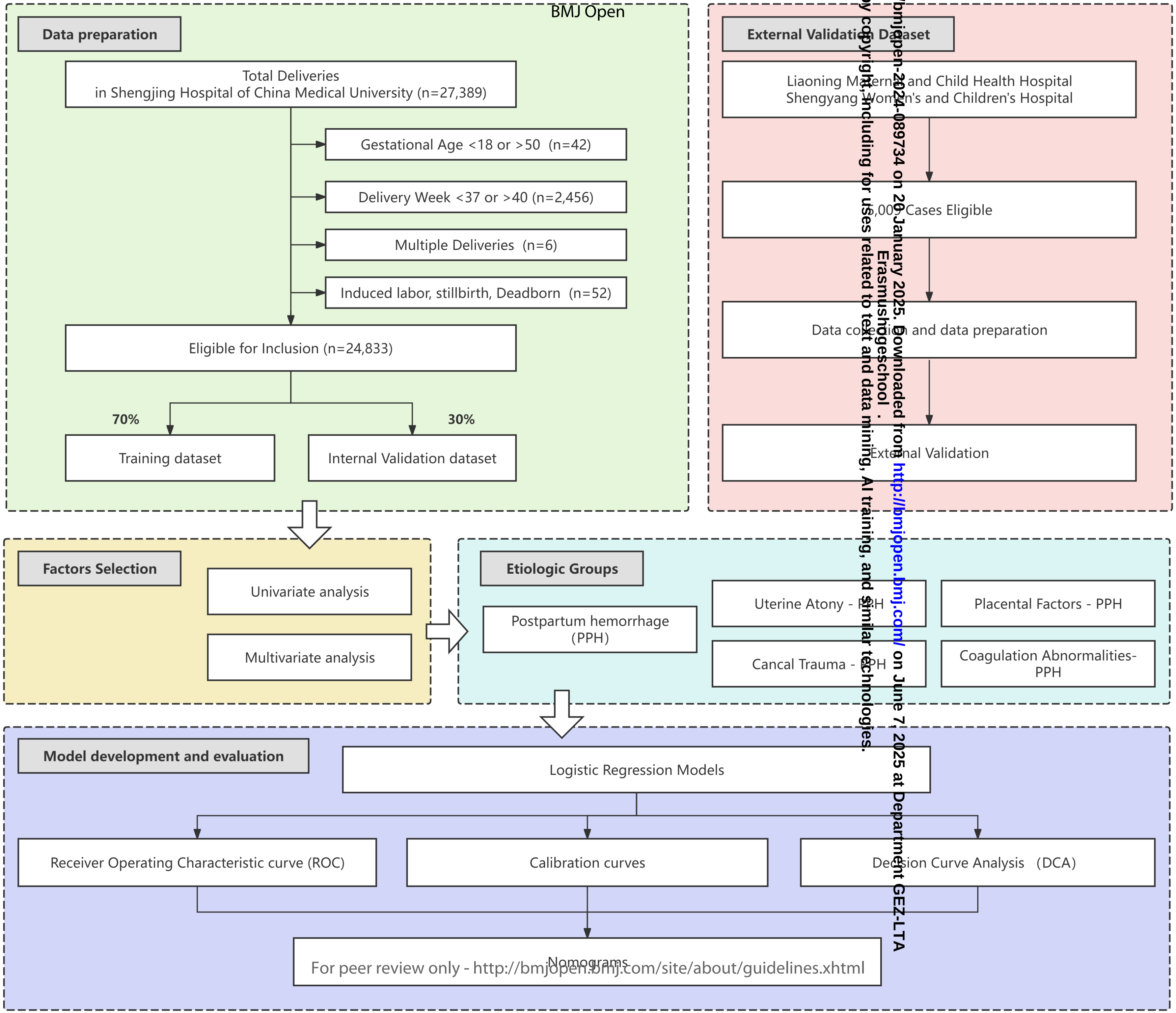
Figure 1. Patient Selection Criteria Flowchart.

Figure 2. AUC Curve for Postpartum Hemorrhage (PPH) Group and four subgroups. A. PPH Group; B. Uterine Atony PPH Group; C. Placental Factors PPH Group; D. Cervical Trauma PPH Group; E. Coagulation Abnormalities PPH Group. The blue line signifies the training dataset, which is employed to evaluate the model's predictive capabilities following the training phases. The green line corresponds to the internal validation dataset, pivotal for refining model parameters and for conducting initial assessments of the model's accuracy. The purple line denotes the external validation dataset, which is utilized to ascertain the model's generalizability and to verify its performance in an independent dataset.

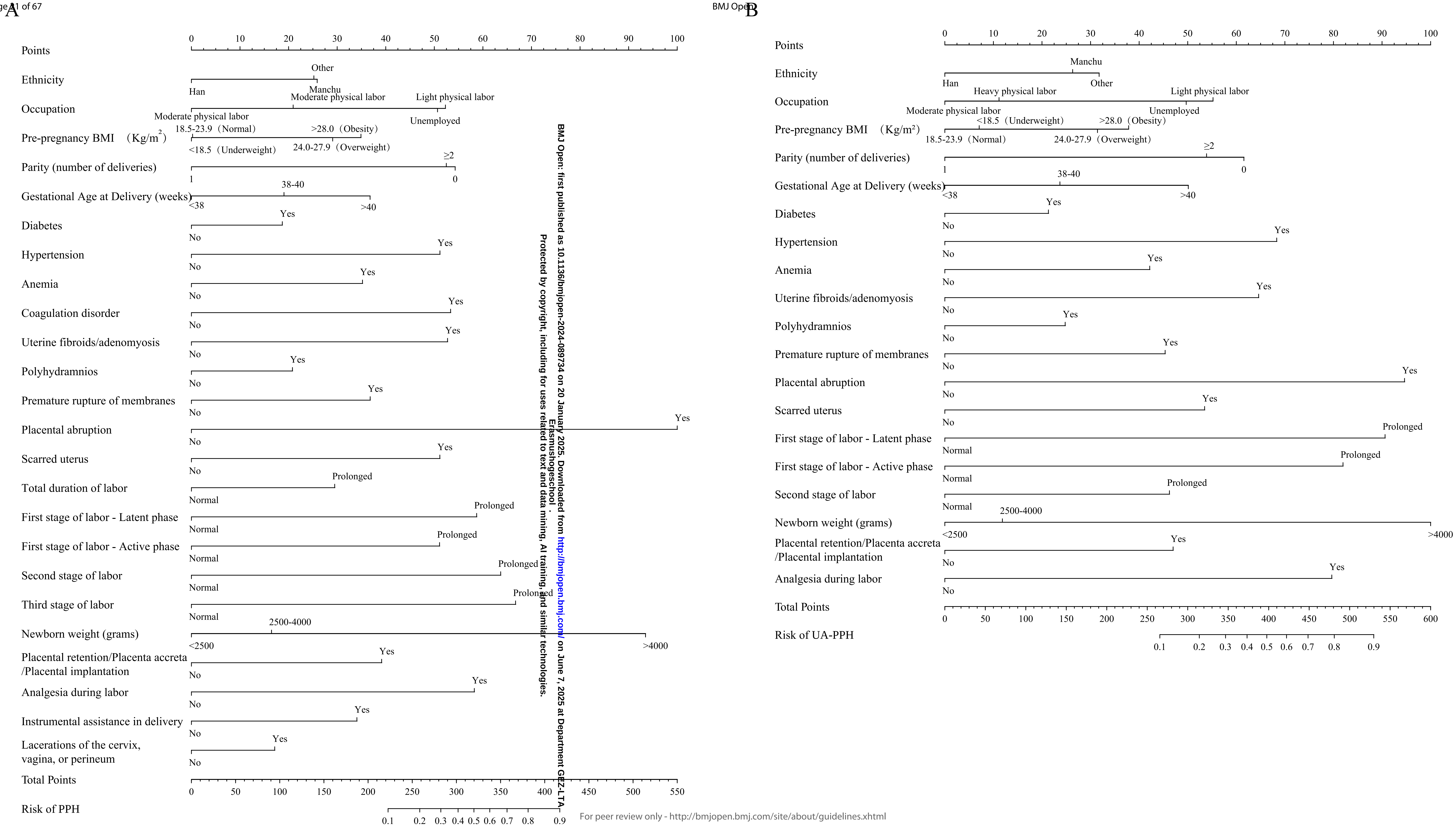
Figure 3. Nomograms for Postpartum Hemorrhage (PPH) and Uterine Atony PPH Group. A. PPH Group; B. Uterine Atony PPH Group.

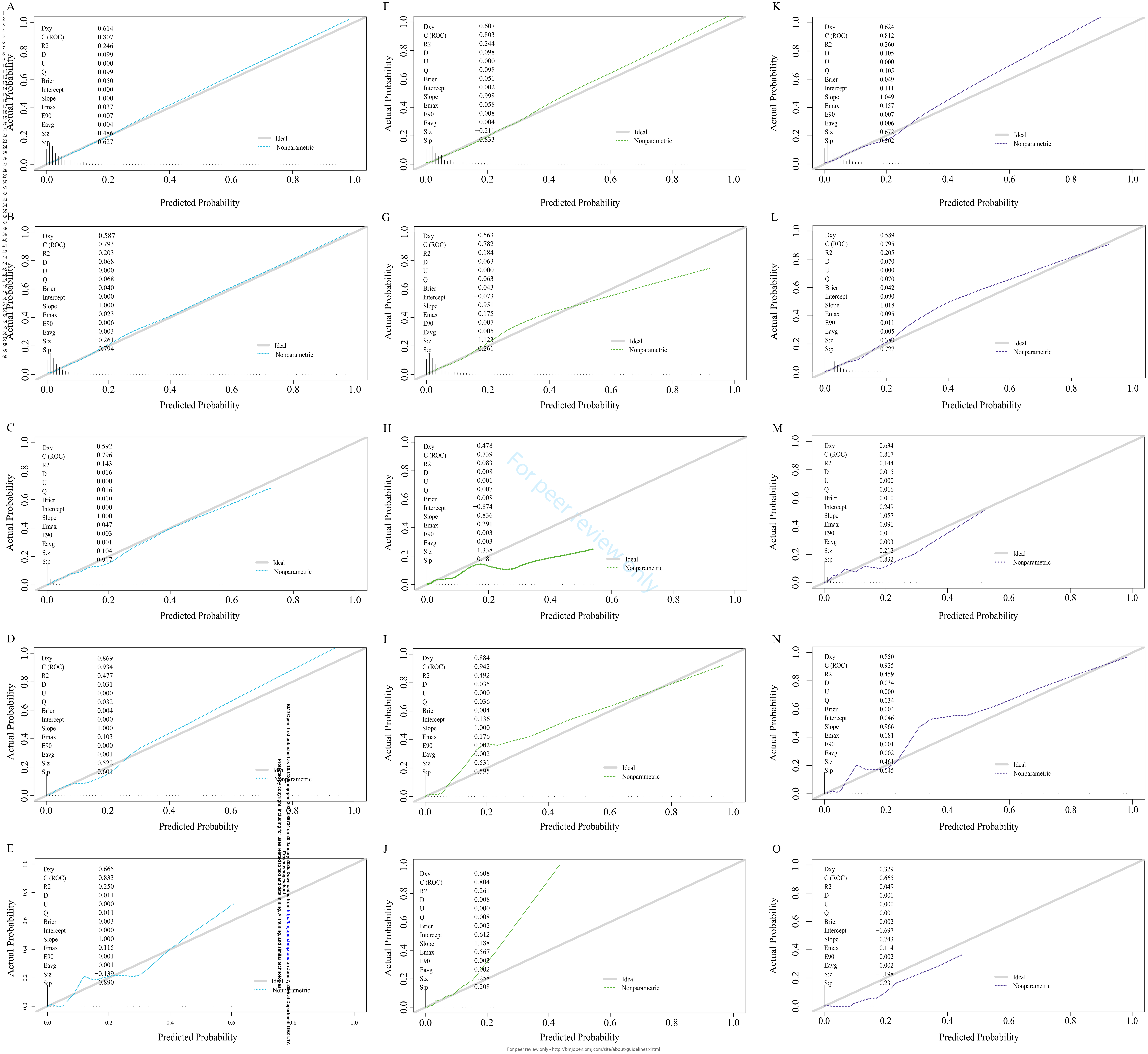
Supplemental Figure 1. Calibration curves for Postpartum Hemorrhage (PPH) Group and four subgroups. A\F\K. PPH Group; B\G\L. Uterine Atony PPH Group; C\H\M. Placental Factors PPH Group; D\I\N. Cervical Trauma PPH Group; E\J\O. Coagulation Abnormalities PPH Group. The blue line signifies the training dataset; The green line signifies the internal validation dataset; The purple line signifies the external validation dataset.

Supplemental Figure 2. Decision Curve Analysis for Postpartum Hemorrhage (PPH) Group and four subgroups. A. PPH Group; B. Uterine Atony PPH Group; C. Placental Factors PPH Group; D. Cervical Trauma PPH Group; E. Coagulation Abnormalities PPH Group. The blue line signifies the training dataset; The green line signifies the internal validation dataset; The purple line signifies the external validation dataset.


Data preparation
Total Deliveries
in Shengjing Hospital of China Medical University (n=27,389)
Gestational Age <18 or >50 (n=42)
Delivery Week <37 or >40 (n=2,456)
Multiple Deliveries (n=6)
Induced labor, stillbirth, Deadborn (n=52)
Eligible for Inclusion (n=24,833)
70%
30%
Training dataset
Internal Validation dataset
External Validation Dataset
Liaoning Maternal and Child Health Hospital
Shengyang Women's and Children's Hospital
Cases Eligible
Data collection and data preparation
External Validation
Factors Selection
Univariate analysis
Multivariate analysis
Etiologic Groups
Postpartum hemorrhage (PPH)
Uterine Atony - PPH
Placental Factors - PPH
Cancal Trauma - PPH
Coagulation Abnormalities-PPH
Model development and evaluation
Logistic Regression Models
Receiver Operating Characteristic curve (ROC)
Calibration curves
Decision Curve Analysis (DCA)
Nomograms


A
Sensitivity
Specificity
AUC: 0.807 (0.792–0.821)
AUC: 0.803 (0.781–0.825)
AUC: 0.812 (0.786–0.838)
B
AUC: 0.794 (0.777–0.811)
AUC: 0.782 (0.756–0.807)
AUC: 0.795 (0.764–0.825)
C
AUC: 0.796 (0.761–0.830)
AUC: 0.739 (0.666–0.813)
AUC: 0.816 (0.750–0.882)
D
AUC: 0.935 (0.901–0.969)
AUC: 0.943 (0.903–0.982)
AUC: 0.926 (0.869–0.982)
E
AUC: 0.831 (0.769–0.892)
AUC: 0.802 (0.655–0.950)
AUC: 0.662 (0.450–0.873)


A
Points
Ethnicity
Han
Other
Manchu
Occupation
Moderate physical labor
Light physical labor
Unemployed
Pre-pregnancy BMI (Kg/m²)
18.5-23.9 (Normal)
>28.0 (Obesity)
<18.5 (Underweight)
24.0-27.9 (Overweight)
Parity (number of deliveries)
≥2
1
0
Gestational Age at Delivery (weeks)
38-40
<38
>40
Diabetes
Hypertension
Anemia
Coagulation disorder
Uterine fibroids/adenomyosis
Polyhydramnios
Premature rupture of membranes
Placental abruption
Scarred uterus
Total duration of labor
First stage of labor - Latent phase
First stage of labor - Active phase
Second stage of labor
Third stage of labor
Yes
No
Prolonged
Normal
Newborn weight (grams)
2500-4000
<2500
>4000
Placental retention/Placenta accreta /Placental implantation
Analgesia during labor
Instrumental assistance in delivery
Lacerations of the cervix, vagina, or perineum
Total Points
Risk of PPH
B
Points
Ethnicity
Han
Manchu
Other
Occupation
Heavy physical labor
Light physical labor
Moderate physical labor
Unemployed
Pre-pregnancy BMI (Kg/m²)
<18.5 (Underweight)
>28.0 (Obesity)
18.5-23.9 (Normal)
24.0-27.9 (Overweight)
Parity (number of deliveries)
Gestational Age at Delivery (weeks)
Diabetes
Hypertension
Anemia
Uterine fibroids/adenomyosis
Polyhydramnios
Premature rupture of membranes
Placental abruption
Scarred uterus
First stage of labor - Latent phase
First stage of labor - Active phase
Second stage of labor
Newborn weight (grams)
Placental retention/Placenta accreta /Placental implantation
Analgesia during labor
Total Points
Risk of UA-PPH


A
Dxy 0.614
C (ROC) 0.807
R2 0.246
D 0.099
U 0.000
Q 0.099
Brier 0.050
Intercept 0.000
Slope 1.000
Emax 0.037
E90 0.007
Eavg 0.004
S:z −0.486
S:p 0.627
B
Dxy 0.587
C (ROC) 0.793
R2 0.203
D 0.068
U 0.000
Q 0.068
Brier 0.040
Intercept 0.000
Slope 1.000
Emax 0.023
E90 0.006
Eavg 0.003
S:z −0.261
S:p 0.794
C
Dxy 0.592
C (ROC) 0.796
R2 0.143
D 0.016
U 0.000
Q 0.016
Brier 0.010
Intercept 0.000
Slope 1.000
Emax 0.047
E90 0.003
Eavg 0.001
S:z 0.104
S:p 0.917
D
Dxy 0.869
C (ROC) 0.934
R2 0.477
D 0.031
U 0.000
Q 0.032
Brier 0.004
Intercept 0.000
Slope 1.000
Emax 0.103
E90 0.000
Eavg 0.001
S:z −0.522
S:p 0.601
E
Dxy 0.665
C (ROC) 0.833
R2 0.250
D 0.011
U 0.000
Q 0.011
Brier 0.003
Intercept 0.000
Slope 1.000
Emax 0.115
E90 0.001
Eavg 0.001
S:z −0.139
S:p 0.890
F
Dxy 0.607
C (ROC) 0.803
R2 0.244
D 0.098
U 0.000
Q 0.098
Brier 0.051
Intercept 0.002
Slope 0.998
Emax 0.058
E90 0.008
Eavg 0.004
S:z −0.211
S:p 0.833
G
Dxy 0.563
C (ROC) 0.782
R2 0.184
D 0.063
U 0.000
Q 0.063
Brier 0.043
Intercept −0.073
Slope 0.951
Emax 0.175
E90 0.007
Eavg 0.005
S:z 1.123
S:p 0.261
H
Dxy 0.478
C (ROC) 0.739
R2 0.083
D 0.008
U 0.001
Q 0.007
Brier 0.008
Intercept −0.874
Slope 0.836
Emax 0.291
E90 0.003
Eavg 0.003
S:z −1.338
S:p 0.181
I
Dxy 0.884
C (ROC) 0.942
R2 0.492
D 0.035
U 0.000
Q 0.036
Brier 0.004
Intercept 0.136
Slope 1.000
Emax 0.176
E90 0.002
Eavg 0.002
S:z 0.531
S:p 0.595
J
Dxy 0.608
C (ROC) 0.804
R2 0.261
D 0.008
U 0.000
Q 0.008
Brier 0.002
Intercept 0.612
Slope 1.188
Emax 0.567
E90 0.003
Eavg 0.002
S:z −1.258
S:p 0.208
K
Dxy 0.624
C (ROC) 0.812
R2 0.260
D 0.105
U 0.000
Q 0.105
Brier 0.049
Intercept 0.111
Slope 1.049
Emax 0.157
E90 0.007
Eavg 0.006
S:z −0.672
S:p 0.502
L
Dxy 0.589
C (ROC) 0.795
R2 0.205
D 0.070
U 0.000
Q 0.070
Brier 0.042
Intercept 0.090
Slope 1.018
Emax 0.095
E90 0.011
Eavg 0.005
S:z 0.350
S:p 0.727
M
Dxy 0.634
C (ROC) 0.817
R2 0.144
D 0.015
U 0.000
Q 0.016
Brier 0.010
Intercept 0.249
Slope 1.057
Emax 0.091
E90 0.011
Eavg 0.003
S:z 0.212
S:p 0.832
N
Dxy 0.850
C (ROC) 0.925
R2 0.459
D 0.034
U 0.000
Q 0.034
Brier 0.004
Intercept 0.046
Slope 0.966
Emax 0.181
E90 0.001
Eavg 0.002
S:z 0.461
S:p 0.645
O
Dxy 0.329
C (ROC) 0.665
R2 0.049
D 0.001
U 0.000
Q 0.001
Brier 0.002
Intercept −1.697
Slope 0.743
Emax 0.114
E90 0.002
Eavg 0.002
S:z −1.198
S:p 0.231
Ideal
Nonparametric
Actual Probability
Predicted Probability
For peer review only


A
Net benefit
Threshold probability
None
All
predict
B
Net benefit
Threshold probability
None
All
predict
C
Net benefit
Threshold probability
None
All
predict
D
Net benefit
Threshold probability
None
All
predict
E
Net benefit
Threshold probability
None
All
predict

Supplementary table 1 Comparison of Basic Characteristics and Risk Factor Screening between Non-PPH and PPH groups

Characteristics	Non-PPH (N=23,210)		PPH (N=1,623)		χ^2	*P*	Univariate Logistic Regression			Multivariate Logistic Regression		
	Sample size	n%	Sample size	n%			OR	95% CI	*P*	OR	95% CI	*P*
General view												
Age (years)					77.07	***<0.001*****						
<25	1,251	5.39%	58	3.57%			Ref.			Ref.		
25-29	11,047	47.60%	689	42.45%			1.35	1.03, 1.79	***0.034****	1.12	0.85, 1.49	0.430
30-34	8,719	37.57%	726	44.73%			1.80	1.38, 2.39	***<0.001*****	1.45	1.11, 1.94	***0.009****
⩾35	2,193	9.45%	150	9.24%			1.48	1.09, 2.03	***0.014****	1.25	0.92, 1.72	0.169
Ethnicity					86.05	***<0.001*****						
Han	20,848	89.82%	1,374	84.66%			Ref.			Ref.		
Manchu	1,693	7.29%	179	11.03%			1.60	1.36, 1.88	***<0.001*****	1.59	1.34, 1.87	***<0.001*****
Other ethnic groups	669	2.88%	70	4.31%			1.59	1.22, 2.03	***<0.001*****	1.62	1.24, 2.07	***<0.001*****
Educational Attainment					39.46	***<0.001*****	Ref.			Ref.		
High school or below	8,142	35.08%	493	30.38%			1.20	1.08, 1.35	***0.001****	0.95	0.84, 1.07	0.392
Bachelor's degree	12,713	54.77%	926	57.05%			1.43	1.21, 1.69	***<0.001*****	1.06	0.88, 1.27	0.520
Postgraduate	2,355	10.15%	204	12.57%								

or higher												
Occupation					359.52	***<0.001****						
Unemployed	10,441	44.98%	932	57.42%			Ref.			Ref.		
Light physical labor	2,573	11.09%	252	15.53%			1.10	0.95, 1.27	0.212	1.07	0.92, 1.24	0.363
Moderate physical labor	9,591	41.32%	420	25.88%			0.49	0.44, 0.55	***<0.001****	0.50	0.44, 0.56	***<0.001****
Heavy physical labor	605	2.61%	19	1.17%			0.35	0.21, 0.54	***<0.001****	0.33	0.20, 0.51	***<0.001****
Family Per Capita Monthly Income (10,000 yuan)					2.98	0.887						
<0.5	9,657	41.61%	668	41.16%			-	-	-	-	-	-
0.5-2.0	8,898	38.34%	636	39.19%			-	-	-	-	-	-
2.0-5.0	3,362	14.49%	222	13.68%			-	-	-	-	-	-
>5.0	1,293	5.57%	97	5.98%			-	-	-	-	-	-
Pre-pregnancy BMI （Kg/m²）					299.11	***<0.001****						
<18.5（Underweight）	6,869	29.60%	425	26.19%			Ref.			Ref.		
18.5-23.9（Normal）	14,116	60.82%	889	54.78%			1.02	0.90, 1.15	0.771	1.02	0.90, 1.15	0.803
24.0-27.9（Overweight）	1,500	6.46%	200	12.32%			2.15	1.80, 2.57	***<0.001****	2.16	1.81, 2.58	***<0.001****

>28.0 （Obesity）	725	3.12%	109	6.72%			2.43	1.93, 3.03	***<0.001*****	2.43	1.93, 3.04	***<0.001*****
Smoking					8.56	***0.036****						
No	23,128	99.65%	1,612	99.32%			Ref.			Ref.		
Yes	82	0.35%	11	0.68%			1.92	0.97, 3.46	***0.042****	[illegible]	0.93, 3.35	0.058
Alcohol Consumption					0.46	0.927						
No	23,153	99.75%	1,620	99.82%			-	-	-	-	-	-
Yes	57	0.25%	3	0.18%			-	-	-	-	-	-
Obstetric and Gynecologic History												
Pregnancy History					46.64	***<0.001*****						
1	13,914	59.95%	1,071	65.99%			Ref.			Ref.		
2	6,153	26.51%	360	22.18%			0.76	0.67, 0.86	***<0.001*****	1.01	0.88, 1.15	0.922
⩾3	3,143	13.54%	192	11.83%			0.79	0.68, 0.93	***0.004****	1.15	0.96, 1.37	0.118
Parity (number of deliveries)					203.39	***<0.001*****						
0	19,060	82.12%	1,490	91.81%			Ref.			Ref.		
1	4,027	17.35%	125	7.70%			0.40	0.33, 0.48	***<0.001*****	0.40	0.32, 0.49	***<0.001*****
⩾2	123	0.53%	8	0.49%			0.83	0.37, 1.60	0.615	0.68	0.29, 1.39	0.331
history of miscarriage					0.16	0.984						
No	17,078	73.58%	1,189	73.26%			-	-	-	-	-	-
Yes	6,132	26.42%	434	26.74%			-	-	-	-	-	-
spontaneous					0.36	0.947						

abortion												
No	20,874	89.94%	1,465	90.26%			-	-	-	-	-	-
Yes	2,336	10.06%	158	9.74%			-	-	-	-	-	-
induced abortion or medication abortion					1.02	0.797						
No	18,688	80.52%	1,295	79.79%			-	-	-	-	-	-
Yes	4,522	19.48%	328	20.21%			-	-	-	-	-	-
induced labor					26.61	*<0.001***						
No	22,717	97.88%	1,609	99.14%			Ref.			Ref.		
Yes	493	2.12%	14	0.86%			0.40	0.22, 0.66	*<0.001***	0.82	0.44, 1.40	0.489
assisted reproductive technology					3.67	0.299						
No	22,595	97.35%	1,589	97.91%			-	-	-	-	-	-
Yes	615	2.65%	34	2.09%			-	-	-	-	-	-
Gestational Age at Delivery (weeks)					241.48	*<0.001***						
<38	1,441	6.21%	66	4.07%			Ref.			Ref.		
38-40	12,349	53.21%	674	41.53%			1.19	0.93, 1.56	0.184	1.52	1.17, 1.99	*0.002**
>40	9,420	40.59%	883	54.41%			2.05	1.60, 2.67	*<0.001***	2.92	2.26, 3.84	*<0.001***
Diabetes					126.81	*<0.001**						

						*						
No	20,207	87.06%	1,300	80.10%			Ref.			Ref.		
Yes	3,003	12.94%	323	19.90%			1.67	1.47, 1.90	*<0.001***	1.62	1.42, 1.84	*<0.001***
Hypertension					284.54	*<0.001***						
No	21,649	93.27%	1,385	85.34%			Ref.			Ref.		
Yes	1,561	6.73%	238	14.66%			2.38	2.05, 2.75	*<0.001***	2.68	2.30, 3.12	*<0.001***
Anemia					223.87	*<0.001***						
No	19,381	83.50%	1,189	73.26%			Ref.			Ref.		
Yes	3,829	16.50%	434	26.74%			1.85	1.65, 2.07	*<0.001***	1.95	1.73, 2.20	*<0.001***
Coagulation disorder					122.64	*<0.001***						
No	23,084	99.46%	1,588	97.84%			Ref.			Ref.		
Yes	126	0.54%	35	2.16%			4.04	2.73, 5.82	*<0.001***	3.82	2.60, 5.77	*<0.001***
Uterine fibroids/adenomyosis					249.58	*<0.001***						
No	22,595	97.35%	1,501	92.48%			Ref.			Ref.		
Yes	615	2.65%	122	7.52%			2.99	2.43, 3.64	*<0.001***	3.08	2.49, 3.79	*<0.001***
Polyhydramnios					58.05	*<0.001***						
No	20,967	90.34%	1,399	86.20%			Ref.			Ref.		
Yes	2,243	9.66%	224	13.80%			1.50	1.29, 1.73	*<0.001***	1.68	1.44, 1.96	*<0.001***
Umbilical cord					0.23	0.973						

entanglement												
No	16,254	70.03%	1,143	70.43%			-	-	-	-	-	-
Yes	6,956	29.97%	480	29.57%			-	-	-	-	-	-
Premature rupture of membranes					336.49	***<0.001*****						
No	18,247	78.62%	1,051	64.76%			Ref.			Ref.		
Yes	4,963	21.38%	572	35.24%			2.00	1.80, 2.22	***<0.001*****	[illegible]	1.92, 2.41	***<0.001*****
Placental abruption					150.97	***<0.001*****						
No	23,180	99.87%	1,605	98.89%			Ref.			Ref.		
Yes	30	0.13%	18	1.11%			8.67	4.73, 15.4	***<0.001*****	8.19	4.28, 15.30	***<0.001*****
Vaginal bleeding during pregnancy					0.73	0.867						
No	22,030	94.92%	1,546	95.26%			-	-	-	-	-	-
Yes	1,180	5.08%	77	4.74%			-	-	-	-	-	-
Scarred uterus					21.53	***<0.001*****						
No	22,980	99.01%	1,593	98.15%			Ref.			Ref.		
Yes	230	0.99%	30	1.85%			1.88	1.26, 2.72	***<0.001****	3.05	1.98, 4.53	***<0.001*****
Delivery Process and Neonatal Conditions												
Time of delivery					0.13	0.989						
Day shift	9,722	41.89%	685	42.21%			-	-	-	-	-	-

Night shift	13,488	58.11%	938	57.79%			-	-	-	-	-	-
Total duration of labor					633.76	*<0.001*****						
normal	22,949	98.88%	1,515	93.35%			Ref.			Ref.		
prolonged	261	1.12%	108	6.65%			6.27	4.96, 7.87	*<0.001***	[illegible]	1.50, 2.78	*<0.001***
First stage of labor - Latent phase					521.17	*<0.001*****						
normal	22,896	98.65%	1,514	93.28%			Ref.			Ref.		
prolonged	314	1.35%	109	6.72%			5.25	4.18, 6.55	*<0.001***	[illegible]	2.44, 4.28	*<0.001***
First stage of labor - Active phase					587.90	*<0.001*****						
normal	22,839	98.40%	1,497	92.24%			Ref.			Ref.		
prolonged	371	1.60%	126	7.76%			5.18	4.19, 6.37	*<0.001***	[illegible]	2.47, 4.03	*<0.001***
Second stage of labor					410.58	*<0.001*****						
normal	23,077	99.43%	1,561	96.18%			Ref.			Ref.		
prolonged	133	0.57%	62	3.82%			6.89	5.05, 9.31	*<0.001***	[illegible]	3.31, 6.76	*<0.001***
Third stage					349.74	*<0.001**						

of labor						*						
normal	23,065	99.38%	1,563	96.30%			Ref.			Ref.		
prolonged	145	0.62%	60	3.70%			6.11	4.47, 8.24	***<0.001*****	4.[illegible]1	3.48, 6.83	***<0.001*****
Placental retention/Placenta accreta/Placental implantation					313.75	***<0.001*****						
No	19,593	84.42%	1,177	72.52%			Ref.			Ref.		
Yes	3,617	15.58%	446	27.48%			2.05	1.83, 2.30	***<0.001*****	2.22	1.96, 2.50	***<0.001*****
Analgesia during labor					392.75	***<0.001*****						
No	22,440	96.68%	1,458	89.83%			Ref.			Ref.		
Yes	770	3.32%	165	10.17%			3.30	2.76, 3.92	***<0.001*****	3.02	2.48, 3.66	***<0.001*****
Instrumental assistance in delivery					196.11	***<0.001*****						
No	22,704	97.82%	1,524	93.90%			Ref.			Ref.		
Yes	506	2.18%	99	6.10%			2.91	2.32, 3.62	***<0.001*****	2.[illegible]0	1.79, 2.93	***<0.001*****
Lacerations of the cervix, vagina, or perineum					88.25	***<0.001*****						
No	21,139	91.08%	1,398	86.14%			Ref.			Ref.		

Yes	2,071	8.92%	225	13.86%			1.64	1.41, 1.90	*<0.001***	1.48	1.26, 1.74	*<0.001***
Newborn weight (grams)					1510.02	*<0.001***						
<2500	221	0.95%	7	0.43%			Ref.			Ref.		
2500-4000	21,944	94.55%	1,281	78.93%			1.84	0.94, 4.34	0.112	[illegible]	0.84, 3.94	0.187
>4000	1,045	4.50%	335	20.64%			10.1	5.09, 24.0	*<0.001***	[illegible]	4.68, 22.40	*<0.001***
Newborn length (centimeters)					52.57	*<0.001***						
⩽55	22,566	97.23%	1,542	95.01%			Ref.			Ref.		
>55	644	2.77%	81	4.99%			1.84	1.44, 2.32	*<0.001***	0.83	0.63, 1.08	0.172

Supplementary table 2 Comparison of Basic Characteristics and Risk Factor Screening between Non-UA-PPH and UA-PPH groups

Characteristics	Non-UA-PPH (N=23,608)		UA-PPH (N=1,225)		χ^2	*P*	Univariate Logistic Regression			Multivariate Logistic Regression		
	Sample size	n%	Sample size	n%			OR	95% CI	*P*	OR	95% CI	*P*
General view												
Age (years)					67.01	***<0.001****						
<25	1,269	5.38%	40	3.27%			Ref.			Ref.		
25-29	11,212	47.49%	524	42.78%			1.48	1.08, 2.09	***0.018****	1.21	0.88, 1.71	0.266
30-34	8,891	37.66%	554	45.22%			1.98	1.45, 2.78	***<0.001*****	1.55	1.13, 2.19	***0.009****
⩾35	2,236	9.47%	107	8.73%			1.52	1.06, 2.22	***0.027****	1.24	0.86, 1.82	0.259
Ethnicity					39.45	***<0.001****						
Han	21,172	89.68%	1,050	85.71%			Ref.			Ref.		
Manchu	1,749	7.41%	123	10.04%			1.42	1.16, 1.71	***<0.001*****	1.40	1.15, 1.70	***<0.001*****
Other ethnic groups	687	2.91%	52	4.24%			1.53	1.13, 2.02	***0.004****	1.55	1.15, 2.05	***0.003****
Educational Attainment					54.87	***<0.001****						
High school or below	8,278	35.06%	357	29.14%			Ref.			Ref.		
Bachelor's degree	12,939	54.81%	700	57.14%			1.25	1.10, 1.43	***<0.001*****	0.99	0.86, 1.13	0.831
Postgraduate	2,391	10.13%	168	13.71%			1.63	1.35, 1.96	***<0.001*****	1.20	0.98, 1.47	0.075

or higher												
Occupation					288.17	***<0.001*** *						
Unemployed	10,672	45.21%	701	57.22%			Ref.			Ref.		
Light physical labor	2,626	11.12%	199	16.24%			1.15	0.98, 1.36	0.086	[illegible]1	0.94, 1.31	0.220
Moderate physical labor	9,701	41.09%	310	25.31%			0.49	0.42, 0.56	***<0.001*** **	0.[illegible]0	0.43, 0.58	***<0.001*** **
Heavy physical labor	609	2.58%	15	1.22%			0.37	0.21, 0.61	***<0.001*** **	0.[illegible]5	0.20, 0.57	***<0.001*** **
Family Per Capita Monthly Income (10,000 yuan)					6.50	0.483						
<0.5	9,824	41.61%	501	40.90%			-	-	-	-	-	-
0.5-2.0	9,052	38.34%	482	39.35%			-	-	-	-	-	-
2.0-5.0	3,421	14.49%	163	13.31%			-	-	-	-	-	-
>5.0	1,311	5.55%	79	6.45%			-	-	-	-	-	-
Pre-pregnancy BMI （Kg/m2）					150.25	***<0.001*** *						
<18.5 （Underweight）	6,949	29.43%	345	28.16%			Ref.			Ref.		
18.5-23.9	14,339	60.74%	666	54.37%			0.94	0.82, 1.07	0.326	0.[illegible]3	0.82, 1.07	0.313

（Normal）												
24.0-27.9 （Overweight ）	1,556	6.59%	144	11.76%			1.86	1.52, 2.28	*<0.001***	1.[illegible]6	1.51, 2.27	*<0.001***
>28.0 （Obesity）	764	3.24%	70	5.71%			1.85	1.40, 2.40	*<0.001***	[illegible]4	1.39, 2.39	*<0.001***
Smoking					2.68	0.444						
No	23,522	99.64%	1,218	99.43%			-	-	-	-	-	-
Yes	86	0.36%	7	0.57%			-	-	-	-	-	-
Alcohol Consumption					0.66	0.883						
No	23,550	99.75%	1,223	99.84%			-	-	-	-	-	-
Yes	58	0.25%	2	0.16%			-	-	-	-	-	-
Obstetric and Gynecologic History												
Pregnancy History					33.29	*<0.001***						
1	14,179	60.06%	806	65.80%			Ref.			Ref.		
2	6,244	26.45%	269	21.96%			0.76	0.66, 0.87	*<0.001***	0.[illegible]8	0.84, 1.14	0.830
⩾3	3,185	13.49%	150	12.24%			0.83	0.69, 0.99	*0.039**	1.[illegible]7	0.95, 1.42	0.131
Parity (number of deliveries)					138.11	*<0.001***						
0	19,431	82.31%	1,119	91.35%			Ref.			Ref.		
1	4,053	17.17%	99	8.08%			0.42	0.34, 0.52	*<0.001***	0.4[illegible]1	0.32, 0.53	*<0.001***
⩾2	124	0.53%	7	0.57%			0.98	0.41, 1.95	0.959	0.[illegible]6	0.31, 1.61	0.513
history of					0.08	0.994						

miscarriage												
No	17,369	73.57%	898	73.31%			-	-	-	-	-	-
Yes	6,239	26.43%	327	26.69%			-	-	-	-	-	-
spontaneous abortion					1.55	0.671						
No	21,228	89.92%	1,111	90.69%			-	-	-	-	-	-
Yes	2,380	10.08%	114	9.31%			-	-	-	-	-	-
induced abortion or medication abortion					2.07	0.559						
No	19,011	80.53%	972	79.35%			-	-	-	-	-	-
Yes	4,597	19.47%	253	20.65%			-	-	-	-	-	-
induced labor					10.41	***0.015****	Ref.			Ref.		
No	23,115	97.91%	1,211	98.86%								
Yes	493	2.09%	14	1.14%			0.54	0.30, 0.89	***0.025****	1.09	0.59, 1.88	0.774
assisted reproductive technology					6.77	0.080						
No	22,981	97.34%	1,203	98.20%			-	-	-	-	-	-
Yes	627	2.66%	22	1.80%			-	-	-	-	-	-
Gestational Age at Delivery (weeks)					189.66	***<0.001*****						

<38	1,458	6.18%	49	4.00%			Ref.			Ref.		
38-40	12,518	53.02%	505	41.22%			1.20	0.90, 1.64	0.230	1.51	1.12, 2.06	***0.008****
>40	9,632	40.80%	671	54.78%			2.07	1.56, 2.82	*<0.001***	2.90	2.16, 3.97	*<0.001***
Diabetes					96.97	*<0.001***						
No	20,527	86.95%	980	80.00%			Ref.			Ref.		
Yes	3,081	13.05%	245	20.00%			1.67	1.44, 1.92	*<0.001***	1.60	1.38, 1.86	*<0.001***
hypertension					256.89	*<0.001***						
No	21,998	93.18%	1,036	84.57%			Ref.			Ref.		
Yes	1,610	6.82%	189	15.43%			2.49	2.11, 2.93	*<0.001***	2.77	2.33, 3.28	*<0.001***
anemia					150.71	*<0.001***						
No	19,667	83.31%	903	73.71%			Ref.			Ref.		
Yes	3,941	16.69%	322	26.29%			1.78	1.56, 2.03	*<0.001***	1.89	1.64, 2.16	*<0.001***
coagulation disorder					0.24	0.972						
No	23,454	99.35%	1,218	99.43%			-	-	-	-	-	-
Yes	154	0.65%	7	0.57%			-	-	-	-	-	-
uterine fibroids/adenomyosis					205.10	*<0.001***						
No	22,966	97.28%	1,130	92.24%			Ref.			Ref.		
Yes	642	2.72%	95	7.76%			3.01	2.39, 3.74	*<0.001***	3.04	2.40, 3.82	*<0.001***
polyhydramnios					50.52	*<0.001***						

No	21,314	90.28%	1,052	85.88%			Ref.			Ref.		
Yes	2,294	9.72%	173	14.12%			1.53	1.29, 1.80	***<0.001****	1.70	1.43, 2.02	***<0.001****
umbilical cord entanglement					0.12	0.989						
No	16,535	70.04%	862	70.37%			-	-	-	-	-	-
Yes	7,073	29.96%	363	29.63%			-	-	-	-	-	-
premature rupture of membranes					220.01	***<0.001****						
No	18,495	78.34%	803	65.55%			Ref.			Ref.		
Yes	5,113	21.66%	422	34.45%			1.90	1.68, 2.15	***<0.001****	2.03	1.79, 2.30	***<0.001****
placental abruption					165.43	***<0.001****						
No	23,576	99.86%	1,209	98.69%			Ref.			Ref.		
Yes	32	0.14%	16	1.31%			9.75	5.21, 17.5	***<0.001****	8.88	4.53, 16.70	***<0.001****
vaginal bleeding during pregnancy					0.14	0.986						
No	22,411	94.93%	1,165	95.10%			-	-	-	-	-	-
Yes	1,197	5.07%	60	4.90%			-	-	-	-	-	-
scarred uterus					13.95	***0.003****						
No	23,370	98.99%	1,203	98.20%			Ref.			Ref.		
Yes	238	1.01%	22	1.80%			1.80	1.12, 2.72	***0.009****	2.72	1.66, 4.26	***<0.001****

Delivery Process and Neonatal Conditions												
Time of delivery					0.29	0.963						
Day shift	9,900	41.93%	507	41.39%			-	-	-	-	-	-
Night shift	13,708	58.07%	718	58.61%			-	-	-	-	-	-
Total duration of labor					433.65	*<0.001***						
normal	23,318	98.77%	1,146	93.55%			Ref.			Ref.		
prolonged	290	1.23%	79	6.45%			5.54	4.27, 7.12	*<0.001***	1.[illegible]1	1.08, 2.11	*0.016**
First stage of labor - Latent phase					548.59	*<0.001***						
normal	23,279	98.61%	1,131	92.33%			Ref.			Ref.		
prolonged	329	1.39%	94	7.67%			5.88	4.62, 7.42	*<0.001***	3.96	2.95, 5.27	*<0.001***
First stage of labor - Active phase					610.26	*<0.001***						
normal	23,219	98.35%	1,117	91.18%			Ref.			Ref.		
prolonged	389	1.65%	108	8.82%			5.77	4.61, 7.18	*<0.001***	3.89	3.01, 4.99	*<0.001***
Second stage of labo					142.00	*<0.001***						

normal	23,448	99.32%	1,190	97.14%			Ref.			Ref.		
prolonged	160	0.68%	35	2.86%			4.31	2.93, 6.16	***<0.001****	2.70	1.75, 4.07	***<0.001****
Third stage of labo					34.84	***<0.001****						
normal	23,426	99.23%	1,202	98.12%			Ref.			Ref.		
prolonged	182	0.77%	23	1.88%			2.46	1.55, 3.73	***<0.001****	[illegible]	0.97, 2.52	0.053
Placental retention/Placenta accreta/Placental implantation					234.09	***<0.001****						
No	19,882	84.22%	888	72.49%			Ref.			Ref.		
Yes	3,726	15.78%	337	27.51%			2.03	1.78, 2.30	***<0.001****	2.13	1.86, 2.44	***<0.001****
Analgesia during labor					317.74	***<0.001****						
No	22,801	96.58%	1,097	89.55%			Ref.			Ref.		
Yes	807	3.42%	128	10.45%			3.30	2.70, 4.00	***<0.001****	3.27	2.65, 4.02	***<0.001****
Instrumental assistance in delivery					7.45	0.059						
No	23,043	97.61%	1,185	96.73%			-	-	-	-	-	-
Yes	565	2.39%	40	3.27%			-	-	-	-	-	-
Lacerations					1.08	0.782						

of the cervix, vagina, or perineum												
No	21,418	90.72%	1,119	91.35%			-	-	-	-	-	-
Yes	2,190	9.28%	106	8.65%			-	-	-	-	-	-
Newborn weight (grams)					953.06	***<0.001***						
<2500	225	0.95%	3	0.24%			Ref.			Ref.		
2500-4000	22,241	94.21%	984	80.33%			3.32	1.26, 13.4	***0.039****	3.[illegible]2	1.14, 12.2	0.058
>4000	1,142	4.84%	238	19.43%			15.6	5.90, 63.5	***<0.001*****	14.41	5.40, 58.90	***<0.001*****
Newborn length (centimeters)					32.72	***<0.001***						
≤55	22,942	97.18%	1,166	95.18%			Ref.			Ref.		
>55	666	2.82%	59	4.82%			1.74	1.31, 2.27	***<0.001*****	0.[illegible]2	0.60, 1.10	0.193

Supplementary table 3 Comparison of Basic Characteristics and Risk Factor Screening between Non-PF-PPH and PF-PPH groups

Characteristics	Non-PF-PPH (N=24,591)		PF-PPH (N=242)		χ^2	*P*	Univariate Logistic Regression			Multivariate Logistic Regression		
	Sample size	n%	Sample size	n%			OR	95% CI	*P*	OR	95% CI	*P*
General view												
Age (years)				11.46	0.120							
<25	1,297	5.27%	12	4.96%			-	-	-	-	-	-
25-29	11,639	47.33%	97	40.08%			-	-	-	-	-	-
30-34	9,340	37.98%	105	43.39%			-	-	-	-	-	-
⩾35	2,315	9.41%	28	11.57%			-	-	-	-	-	-
Ethnicity					29.18	***<0.001*****						
Han	22,023	89.56%	199	82.23%			Ref.			Ref.		
Manchu	1,839	7.48%	33	13.64%			1.99	1.35, 2.84	***<0.001*****	1.94	1.32, 2.78	***<0.001*****
Other ethnic groups	729	2.96%	10	4.13%			1.52	0.75, 2.73	0.201	1.55	0.76, 2.78	0.181
Educational Attainment					3.44	0.632						
High school or below	8,559	34.81%	76	31.40%			-	-	-	-	-	-
Bachelor's degree	13,496	54.88%	143	59.09%			-	-	-	-	-	-
Postgraduate or higher	2,536	10.31%	23	9.50%			-	-	-	-	-	-

Occupation					77.00	***<0.001****						
Unemployed	11,218	45.62%	155	64.05%			Ref.			Ref.		
Light physical labor	2,796	11.37%	29	11.98%			0.75	0.49, 1.10	0.159	0.74	0.49, 1.08	0.137
Moderate physical labor	9,955	40.48%	56	23.14%			0.41	0.30, 0.55	***<0.001****	0.41	0.30, 0.55	***<0.001****
Heavy physical labor	622	2.53%	2	0.83%			0.23	0.04, 0.73	***0.041****	0.23	0.04, 0.71	***0.038****
Family Per Capita Monthly Income (10,000 yuan)					2.01	0.959						
<0.5	10,222	41.57%	103	42.56%			-	-	-	-	-	-
0.5-2.0	9,440	38.39%	94	38.84%			-	-	-	-	-	-
2.0-5.0	3,549	14.43%	35	14.46%			-	-	-	-	-	-
>5.0	1,380	5.61%	10	4.13%			-	-	-	-	-	-
Pre-pregnancy BMI （Kg/m2）					64.09	***<0.001****						
<18.5 （Underweight）	7,235	29.42%	59	24.38%			Ref.			Ref.		
18.5-23.9 （Normal）	14,873	60.48%	132	54.55%			1.09	0.80, 1.49	0.590	1.09	0.81, 1.50	0.578

24.0-27.9 （Overweight ）	1,667	6.78%	33	13.64%			2.43	1.56, 3.70	***<0.001***	2.45	1.58, 3.75	***<0.001***
>28.0 （Obesity）	816	3.32%	18	7.44%			2.71	1.54, 4.51	***<0.001***	2.72	1.55, 4.55	***<0.001***
Smoking					2.68	0.444						
No	24,500	99.63%	240	99.17%			-	-	-	-	-	-
Yes	91	0.37%	2	0.83%			-	-	-	-	-	-
Alcohol Consumption					0.60	0.897	-	-	-	-	-	-
No	24,532	99.76%	241	99.59%								
Yes	59	0.24%	1	0.41%								
Obstetric and Gynecologic History												
Pregnancy History					14.33	***<0.001***						
1	14,822	60.27%	163	67.36%			Ref.			Ref.		
2	6,454	26.25%	59	24.38%			0.83	0.61, 1.11	0.226	1.11	0.80, 1.51	0.519
⩾3	3,315	13.48%	20	8.26%			0.55	0.33, 0.85	***0.012****	0.80	0.47, 1.28	0.369
Parity (number of deliveries)					39.16	***<0.001***						
0	20,324	82.65%	226	93.39%			Ref.			Ref.		
1	4,137	16.82%	15	6.20%			0.33	0.18, 0.53	***<0.001***	0.36	0.20, 0.63	***<0.001***
⩾2	130	0.53%	1	0.41%			0.69	0.04, 3.11	0.714	0.[illegible]2	0.05, 4.55	0.933
history of miscarriage					0.17	0.982						

No	18,087	73.55%	180	74.38%			-	-	-	-	-	-
Yes	6,504	26.45%	62	25.62%			-	-	-	-	-	-
spontaneous abortion					0.04	0.998						
No	22,122	89.96%	217	89.67%			-	-	-	-	-	-
Yes	2,469	10.04%	25	10.33%			-	-	-	-	-	-
induced abortion or medication abortion					0.27	0.965						
No	19,786	80.46%	197	81.40%			-	-	-	-	-	-
Yes	4,805	19.54%	45	18.60%			-	-	-	-	-	-
induced labor					6.48	0.090						
No	24,085	97.94%	241	99.59%			-	-	-	-	-	-
Yes	506	2.06%	1	0.41%			-	-	-	-	-	-
assisted reproductive technology					2.34	0.504						
No	23,951	97.40%	233	96.28%			-	-	-	-	-	-
Yes	640	2.60%	9	3.72%			-	-	-	-	-	-
Gestational Age at Delivery (weeks)					26.69	***<0.001*** **						
<38	1,499	6.10%	8	3.31%			Ref.			Ref.		

38-40	12,916	52.52%	107	44.21%			1.55	0.81, 3.47	0.231	1.[illegible]9	0.98, 4.24	0.085
>40	10,176	41.38%	127	52.48%			2.34	1.22, 5.21	***0.020***[*]	3.[illegible]0	1.60, 6.97	***0.002***[*]
Diabetes					30.50	***<0.001***[**]						
No	21,318	86.69%	189	78.10%			Ref.			Ref.		
Yes	3,273	13.31%	53	21.90%			1.83	1.33, 2.46	***<0.001***[**]	1.[illegible]6	1.28, 2.38	***<0.001***[**]
hypertension					26.00	***<0.001***[**]						
No	22,824	92.81%	210	86.78%			Ref.			Ref.		
Yes	1,767	7.19%	32	13.22%			1.97	1.33, 2.82	***<0.001***[**]	2.[illegible]2	1.43, 3.06	***<0.001***[**]
anemia					29.60	***<0.001***[**]						
No	20,392	82.92%	178	73.55%			Ref.			Ref.		
Yes	4,199	17.08%	64	26.45%			1.75	1.30, 2.31	***<0.001***[**]	1.[illegible]9	1.33, 2.39	***<0.001***[**]
coagulation disorder					0.24	0.971						
No	24,432	99.35%	240	99.17%			-	-	-	-	-	-
Yes	159	0.65%	2	0.83%			-	-	-	-	-	-
uterine fibroids/adenomyosis					27.94	***<0.001***[**]						
No	23,871	97.07%	225	92.98%			Ref.			Ref.		
Yes	720	2.93%	17	7.02%			2.50	1.47, 4.00	***<0.001***[**]	2.[illegible]4	1.42, 3.92	***<0.001***[**]
polyhydramnios					9.25	***0.026***[*]						
No	22,158	90.11%	208	85.95%			Ref.			Ref.		

Yes	2,433	9.89%	34	14.05%			1.49	1.02, 2.11	***0.033****	1.[illegible]0	1.09, 2.29	***0.013****
umbilical cord entanglement					0.09	0.993						
No	17,229	70.06%	168	69.42%			-	-	-	-	-	-
Yes	7,362	29.94%	74	30.58%			-	-	-	-	-	-
premature rupture of membranes					46.49	***<0.001**** *						
No	19,141	77.84%	157	64.88%			Ref.			Ref.		
Yes	5,450	22.16%	85	35.12%			1.90	1.45, 2.47	***<0.001*****	1.[illegible]6	1.49, 2.57	***<0.001*****
placental abruption					1.23	0.747						
No	24,544	99.81%	241	99.59%			-	-	-	-	-	-
Yes	47	0.19%	1	0.41%			-	-	-	-	-	-
vaginal bleeding during pregnancy					0.88	0.831						
No	23,344	94.93%	232	95.87%			-	-	-	-	-	-
Yes	1,247	5.07%	10	4.13%			-	-	-	-	-	-
scarred uterus					4.90	0.179						
No	24,336	98.96%	237	97.93%			-	-	-	-	-	-
Yes	255	1.04%	5	2.07%			-	-	-	-	-	-
Delivery Process and Neonatal Conditions												

Time of delivery					3.84	0.279						
Day shift	10,295	41.86%	112	46.28%			-	-	-	-	-	-
Night shift	14,296	58.14%	130	53.72%			-	-	-	-	-	-
Total duration of labor					61.71	***<0.001*** **						
normal	24,236	98.56%	228	94.21%			Ref.			Ref.		
prolonged	355	1.44%	14	5.79%			4.19	2.31, 7.00	***<0.001*** **	3.[illegible]6	1.49, 5.88	***0.001*** *
First stage of labor - Latent phase					11.86	***0.008*** *						
normal	24,177	98.32%	233	96.28%			Ref.			Ref.		
prolonged	414	1.68%	9	3.72%			2.26	1.07, 4.16	***0.018*** *	1.[illegible]4	0.48, 2.41	0.749
First stage of labor - Active phase					0.57	0.903						
normal	24,100	98.00%	236	97.52%			-	-	-	-	-	-
prolonged	491	2.00%	6	2.48%			-	-	-	-	-	-
Second stage of labo					54.00	***<0.001*** **						
normal	24,405	99.24%	233	96.28%			Ref.			Ref.		

prolonged	186	0.76%	9	3.72%			5.07	2.38, 9.45	***<0.001******	3.30	1.54, 7.05	***0.001****
Third stage of labo					1178.60	***<0.001******						
normal	24,422	99.31%	206	85.12%			Ref.			Ref.		
prolonged	169	0.69%	36	14.88%			25.31	17.03, 36.72	***<0.001******	27.00	17.51, 40.72	***<0.001******
Placental retention/Placenta accreta/Placental implantation					33.41	***<0.001******						
No	20,591	83.73%	179	73.97%			Ref.			Ref.		
Yes	4,000	16.27%	63	26.03%			1.81	1.35, 2.40	***<0.001******	1.93	1.43, 2.58	***<0.001******
Analgesia during labor					18.20	***<0.001******						
No	23,674	96.27%	224	92.56%			Ref.			Ref.		
Yes	917	3.73%	18	7.44%			2.07	1.23, 3.27	***0.003****	0.94	0.52, 1.60	0.835
Instrumental assistance in delivery					3.38	0.336						
No	23,995	97.58%	233	96.28%			-	-	-	-	-	-
Yes	596	2.42%	9	3.72%			-	-	-	-	-	-
Lacerations of the cervix,					7.40	0.060						

vagina, or perineum												
No	22,326	90.79%	211	87.19%			-	-	-	-	-	-
Yes	2,265	9.21%	31	12.81%			-	-	-	-	-	-
Newborn weight (grams)					212.47	***<0.001****						
<2500	226	0.92%	2	0.83%			Ref.			Ref.		
2500-4000	23,035	93.67%	190	78.51%			0.93	0.30, 5.65	0.922	0.[illegible]8	0.27, 5.39	0.860
>4000	1,330	5.41%	50	20.66%			4.25	1.31, 26.1	***0.046****	4.[illegible]8	1.21, 24.90	0.059
Newborn length (centimeters)					1.10	0.777						
⩽55	23,875	97.09%	233	96.28%			-	-	-	-	-	-
>55	716	2.91%	9	3.72%			-	-	-	-	-	-

Supplementary table 4 Comparison of Basic Characteristics and Risk Factor Screening between Non-CT-PPH and CT-PPH groups

Characteristics	Non-CT-PPH (N=24,694)		CT-PPH (N=139)		χ^2	*P*	Univariate Logistic Regression			Multivariate Logistic Regression		
	Sample size	n%	Sample size	n%			OR	95% CI	*P*	OR	95% CI	*P*
General view												
Age (years)					11.23	0.129						
<25	1,303	5.28%	6	4.32%			-	-	-	-	-	-
25-29	11,682	47.31%	54	38.85%			-	-	-	-	-	-
30-34	9,379	37.98%	66	47.48%			-	-	-	-	-	-
⩾35	2,330	9.44%	13	9.35%			-	-	-	-	-	-
Ethnicity					24.67	***<0.001****						
Han	22,109	89.53%	113	81.29%			Ref.			Ref.		
Manchu	1,856	7.52%	16	11.51%			1.69	0.96, 2.77	0.051	1.67	0.95, 2.75	0.057
Other ethnic groups	729	2.95%	10	7.19%			2.68	1.31, 4.89	***0.003****	2.71	1.32, 4.95	***0.003****
Educational Attainment					4.25	0.515						
High school or below	8,585	34.77%	50	35.97%			-	-	-	-	-	-
Bachelor's degree	13,569	54.95%	70	50.36%			-	-	-	-	-	-
Postgraduate or higher	2,540	10.29%	19	13.67%			-	-	-	-	-	-

Occupation					10.34	0.170						
Unemployed	11,307	45.79%	66	47.48%			-	-	-	-	-	-
Light physical labor	2,802	11.35%	23	16.55%			-	-	-	-	-	-
Moderate physical labor	9,963	40.35%	48	34.53%			-	-	-	-	-	-
Heavy physical labor	622	2.52%	2	1.44%			-	-	-	-	-	-
Family Per Capita Monthly Income (10,000 yuan)					4.07	0.772						
<0.5	10,261	41.55%	64	46.04%			-	-	-	-	-	-
0.5-2.0	9,481	38.39%	53	38.13%			-	-	-	-	-	-
2.0-5.0	3,569	14.45%	15	10.79%			-	-	-	-	-	-
>5.0	1,383	5.60%	7	5.04%			-	-	-	-	-	-
Pre-pregnancy BMI （Kg/m2）					270.37	***<0.001*** **						
<18.5（Underweight）	7,274	29.46%	20	14.39%			Ref.			Ref.		
18.5-23.9（Normal）	14,939	60.50%	66	47.48%			1.61	0.99, 2.72	0.064	1.60	0.99, 2.72	0.064
24.0-27.9	1,671	6.77%	29	20.86%			6.31	3.58, 11.30	***<0.001*** **	6.33	3.59, 11.40	***<0.001*** **

（Overweight）												
>28.0 （Obesity）	810	3.28%	24	17.27%			10.80	5.93, 19.82	***<0.001*****	10.70	5.91, 19.71	***<0.001*****
Smoking					1.05	0.789						
No	24,601	99.62%	139	100.00 %			-	-	-	-	-	-
Yes	93	0.38%	0	0.00%			-	-	-	-	-	-
Alcohol Consumption					0.68	0.879						
No	24,634	99.76%	139	100.00 %			-	-	-	-	-	-
Yes	60	0.24%	0	0.00%			-	-	-	-	-	-
Obstetric and Gynecologic History												
Pregnancy History					8.22	0.145						
1	14,892	60.31%	93	66.91%			-	-	-	-	-	-
2	6,487	26.27%	26	18.71%			-	-	-	-	-	-
⩾3	3,315	13.42%	20	14.39%			-	-	-	-	-	-
Parity (number of deliveries)					18.31	***0.003****						
0	20,422	82.70%	128	92.09%			Ref.			Ref.		
1	4,142	16.77%	10	7.19%			0.39	0.19, 0.70	***0.004****	0.40	0.20, 0.73	***0.006****
⩾2	130	0.53%	1	0.72%			1.23	0.07, 5.54	0.839	1.25	0.07, 5.70	0.824
history of					0.38	0.945						

miscarriage												
No	18,167	73.57%	100	71.94%			-	-	-	-	-	-
Yes	6,527	26.43%	39	28.06%			-	-	-	-	-	-
spontaneous abortion					0.67	0.881						
No	22,216	89.97%	123	88.49%			-	-	-	-	-	-
Yes	2,478	10.03%	16	11.51%			-	-	-	-	-	-
induced abortion or medication abortion					0.07	0.996						
No	19,872	80.47%	111	79.86%			-	-	-	-	-	-
Yes	4,822	19.53%	28	20.14%			-	-	-	-	-	-
induced labor					0.51	0.917						
No	24,189	97.95%	137	98.56%			-	-	-	-	-	-
Yes	505	2.05%	2	1.44%			-	-	-	-	-	-
assisted reproductive technology					1.52	0.679						
No	24,047	97.38%	137	98.56%			-	-	-	-	-	-
Yes	647	2.62%	2	1.44%			-	-	-	-	-	-
Gestational Age at Delivery (weeks)					22.32	*<0.001***						

<38	1,501	6.08%	6	4.32%			Ref.			Ref.		
38-40	12,967	52.51%	56	40.29%			1.08	0.50, 2.81	0.857	-	-	-
>40	10,226	41.41%	77	55.40%			1.88	0.89, 4.86	0.136	-	-	-
Diabetes					10.98	***0.012****						
No	21,396	86.64%	111	79.86%			Ref.			Ref.		
Yes	3,298	13.36%	28	20.14%			1.64	1.06, 2.44	***0.020****	1.[illegible]3	0.99, 2.29	***0.045****
hypertension					10.34	***0.016****						
No	22,912	92.78%	122	87.77%			Ref.			Ref.		
Yes	1,782	7.22%	17	12.23%			1.79	1.04, 2.90	***0.025****	1.[illegible]3	1.06, 2.97	***0.021****
anemia					23.32	***<0.001*****						
No	20,470	82.89%	100	71.94%			Ref.			Ref.		
Yes	4,224	17.11%	39	28.06%			1.89	1.29, 2.72	***<0.001*****	1.[illegible]8	1.28, 2.71	***<0.001*****
coagulation disorder					0.02	0.999						
No	24,534	99.35%	138	99.28%			-	-	-	-	-	-
Yes	160	0.65%	1	0.72%			-	-	-	-	-	-
uterine fibroids/adenomyosis					17.34	***<0.001*****						
No	23,967	97.06%	129	92.81%			Ref.			Ref.		
Yes	727	2.94%	10	7.19%			2.56	1.25, 4.64	***0.005****	2.[illegible]4	1.19, 4.43	***0.007****
polyhydramnios					6.20	0.102						
No	22,247	90.09%	119	85.61%			-	-	-	-	-	-
Yes	2,447	9.91%	20	14.39%			-	-	-	-	-	-

umbilical cord entanglement					4.01	0.261						
No	17,292	70.03%	105	75.54%			-	-	-	-	-	-
Yes	7,402	29.97%	34	24.46%			-	-	-	-	-	-
premature rupture of membranes					24.20	***<0.001****						
No	19,207	77.78%	91	65.47%			Ref.			Ref.		
Yes	5,487	22.22%	48	34.53%			1.85	1.29, 2.61	***<0.001****	1.70	1.19, 2.41	***0.003****
placental abruption					4.01	0.260						
No	24,647	99.81%	138	99.28%			-	-	-	-	-	-
Yes	47	0.19%	1	0.72%			-	-	-	-	-	-
vaginal bleeding during pregnancy					0.28	0.964						
No	23,445	94.94%	131	94.24%			-	-	-	-	-	-
Yes	1,249	5.06%	8	5.76%			-	-	-	-	-	-
scarred uterus					0.41	0.937						
No	24,436	98.96%	137	98.56%			-	-	-	-	-	-
Yes	258	1.04%	2	1.44%			-	-	-	-	-	-
Delivery Process and Neonatal Conditions												
Time of					0.30	0.960						

delivery												
Day shift	10,351	41.92%	56	40.29%			-	-	-	-	-	-
Night shift	14,343	58.08%	83	59.71%			-	-	-	-	-	-
Total duration of labor					97.56	***<0.001*****						
normal	24,337	98.55%	127	91.37%			Ref.			Ref.		
prolonged	357	1.45%	12	8.63%			6.44	3.35, 11.3	***<0.001*****	2.[illegible]9	0.99, 7.48	***0.045****
First stage of labor - Latent phase					18.54	***<0.001*****						
normal	24,278	98.32%	132	94.96%			Ref.			Ref.		
prolonged	416	1.68%	7	5.04%			3.09	1.30, 6.18	***0.004****	1.42	0.46, 3.75	0.514
First stage of labor - Active phase					77.03	***<0.001*****						
normal	24,210	98.04%	126	90.65%			Ref.			Ref.		
prolonged	484	1.96%	13	9.35%			5.16	2.76, 8.85	***<0.001*****	1.66	0.65, 3.87	0.266
Second stage of labo					974.69	***<0.001*****						
normal	24,523	99.31%	115	82.73%			Ref.			Ref.		
prolonge	171	0.69%	24	17.27%			29.9	18.42, 46.90	***<0.001*****	36.04	17.40, 72.31	***<0.001*****

d												
Third stage of labo					41.62	***<0.001*** *						
normal	24,495	99.19%	133	95.68%			Ref.			Ref.		
prolonged	199	0.81%	6	4.32%			5.55	2.16, 11.7	***<0.001*** **	[illegible]	1.43, 15.11	***0.005*** *
Placental retention/Placenta accreta/Placental implantation					31.49	***<0.001*** *						
No	20,671	83.71%	99	71.22%			Ref.			Ref.		
Yes	4,023	16.29%	40	28.78%			2.08	1.42, 2.98	***<0.001*** **	2.[illegible]8	1.48, 3.77	***<0.001*** **
Analgesia during labor					46.29	***<0.001*** *						
No	23,775	96.28%	123	88.49%			Ref.			Ref.		
Yes	919	3.72%	16	11.51%			3.37	1.92, 5.52	***<0.001*** **	2.22	1.03, 4.46	***0.032*** *
Instrumental assistance in delivery					2311.00	***<0.001*** *						
No	24,154	97.81%	74	53.24%			Ref.			Ref.		
Yes	540	2.19%	65	46.76%			39.31	27.80, 55.41	***<0.001*** **	27.[illegible]1	17.80, 43.22	***<0.001*** **
Lacerations of the cervix, vagina, or					1561.20	***<0.001*** *						

perineum												
No	22,506	91.14%	31	22.30%			Ref.			Ref.		
Yes	2,188	8.86%	108	77.70%			35.82	24.3, 54.4	***<0.001*****	37.42	23.80, 61.01	***<0.001*****
Newborn weight (grams)					669.48	***<0.001*** **						
<2500	227	0.92%	1	0.72%			Ref.			Ref.		
2500-4000	23,144	93.72%	81	58.27%			0.79	0.18, 14.0	0.820	[illegible]	0.12, 12.3	0.689
>4000	1,323	5.36%	57	41.01%			9.78	2.14, 173	***0.024****	[illegible]	1.15, 120	0.089
Newborn length (centimeters)					18.02	***<0.001*** **						
⩽55	23,979	97.10%	129	92.81%			Ref.			Ref.		
>55	715	2.90%	10	7.19%			2.60	1.27, 4.72	***0.004****	[illegible]	0.47, 2.50	0.762

Supplementary table 5 Comparison of Basic Characteristics and Risk Factor Screening between Non-CA-PPH and CA-PPH groups

Characteristics	Non-CA-PPH (N=24,757)		CA-PPH (N=76)		χ^2	*P*	Univariate Logistic Regression			Multivariate Logistic Regression		
	Sample size	n%	Sample size	n%			OR	95% CI	*P*	OR	95% CI	*P*
General view												
Age (years)					6.09	0.530						
<25	1,308	5.28%	1	1.32%			-	-	-	-	-	-
25-29	11,702	47.27%	34	44.74%			-	-	-	-	-	-
30-34	9,412	38.02%	33	43.42%			-	-	-	-	-	-
⩾35	2,335	9.43%	8	10.53%			-	-	-	-	-	-
Ethnicity					6.92	0.227						
Han	22,158	89.50%	64	84.21%			-	-	-	-	-	-
Manchu	1,862	7.52%	10	13.16%			-	-	-	-	-	-
Other ethnic groups	737	2.98%	2	2.63%			-	-	-	-	-	-
Educational Attainment					1.65	0.895						
High school or below	8,611	34.78%	24	31.58%			-	-	-	-	-	-
Bachelor's degree	13,597	54.92%	42	55.26%			-	-	-	-	-	-
Postgraduate or higher	2,549	10.30%	10	13.16%			-	-	-	-	-	-
Occupation					21.85	***0.003****						

Unemployed	11,330	45.76%	43	56.58%			Ref.			Ref.		
Light physical labor	2,811	11.35%	14	18.42%			1.31	0.69, 2.34	0.378	1.29	0.68, 2.30	0.411
Moderate physical labor	9,993	40.36%	18	23.68%			0.47	0.27, 0.81	***0.008******	0.48	0.27, 0.81	***0.008******
Heavy physical labor	623	2.52%	1	1.32%			0.42	0.02, 1.94	0.395	0.42	0.02, 1.93	0.393
Family Per Capita Monthly Income (10,000 yuan)					6.42	0.492						
<0.5	10,297	41.59%	28	36.84%			-	-	-	-	-	-
0.5-2.0	9,503	38.39%	31	40.79%			-	-	-	-	-	-
2.0-5.0	3,569	14.42%	15	19.74%			-	-	-	-	-	-
>5.0	1,388	5.61%	2	2.63%			-	-	-	-	-	-
Pre-pregnancy BMI （Kg/m2）					15.86	***0.026******						
<18.5 （Underweight）	7,282	29.41%	12	15.79%			Ref.			Ref.		
18.5-23.9 （Normal）	14,953	60.40%	52	68.42%			2.11	1.17, 4.15	***0.020******	2.09	1.16, 4.11	***0.021******
24.0-27.9 （Overweight	1,692	6.83%	8	10.53%			2.87	1.12, 6.95	***0.021******	2.88	1.12, 6.97	***0.021******

)												
>28.0 （Obesity）	830	3.35%	4	5.26%			2.92	0.82, 8.42	0.064	2.93	0.82, 8.43	0.064
Smoking					20.82	***<0.001***[*][*]						
No	24,666	99.63%	74	97.37%			Ref.			Ref.		
Yes	91	0.37%	2	2.63%			7.33	1.19, 23.81	***0.006***[*]	4.63	1.08, 21.70	***0.009***[*]
Alcohol Consumption					0.37	0.947						
No	24,697	99.76%	76	100.00 %			-	-	-	-	-	-
Yes	60	0.24%	0	0.00%			-	-	-	-	-	-
Obstetric and Gynecologic History												
Pregnancy History					7.08	0.215						
1	14,932	60.31%	53	69.74%			-	-	-	-	-	-
2	6,500	26.26%	13	17.11%			-	-	-	-	-	-
⩾3	3,325	13.43%	10	13.16%			-	-	-	-	-	-
Parity (number of deliveries)					15.86	***0.007***[*]						
0	20,479	82.72%	71	93.42%			Ref.			Ref.		
1	4,148	16.75%	4	5.26%			0.28	0.08, 0.67	***0.013***[*]	0.27	0.08, 0.68	***0.014***[*]
⩾2	130	0.53%	1	1.32%			2.22	0.13, 10.1	0.431	2.56	0.14, 13.3	0.375
history of miscarriage					0.16	0.983						

No	18,210	73.55%	57	75.00%			-	-	-	-	-	-
Yes	6,547	26.45%	19	25.00%			-	-	-	-	-	-
spontaneous abortion					0.04	0.998						
No	22,271	89.96%	68	89.47%			-	-	-	-	-	-
Yes	2,486	10.04%	8	10.53%			-	-	-	-	-	-
induced abortion or medication abortion					0.57	0.903						
No	19,920	80.46%	63	82.89%			-	-	-	-	-	-
Yes	4,837	19.54%	13	17.11%			-	-	-	-	-	-
induced labor					3.18	0.365						
No	24,250	97.95%	76	100.00%			-	-	-	-	-	-
Yes	507	2.05%	0	0.00%			-	-	-	-	-	-
assisted reproductive technology					0.02	0.999						
No	24,110	97.39%	74	97.37%			-	-	-	-	-	-
Yes	647	2.61%	2	2.63%			-	-	-	-	-	-
Gestational Age at Delivery (weeks)					14.46	***0.013****						

<38	1,503	6.07%	4	5.26%			Ref.			Ref.		
38-40	12,994	52.49%	29	38.16%			0.84	0.33, 2.83	0.742	-	-	-
>40	10,260	41.44%	43	56.58%			1.57	0.64, 5.24	0.386	-	-	-
Diabetes					0.75	0.860						
No	21,443	86.61%	64	84.21%			-	-	-	-	-	-
Yes	3,314	13.39%	12	15.79%			-	-	-	-	-	-
hypertension					2.44	0.486						
No	22,966	92.77%	68	89.47%			-	-	-	-	-	-
Yes	1,791	7.23%	8	10.53%			-	-	-	-	-	-
anemia					18.39	***<0.001*****						
No	20,517	82.87%	53	69.74%			Ref.			Ref.		
Yes	4,240	17.13%	23	30.26%			2.10	1.26, 3.38	***0.003****	1.93	1.13, 3.20	***0.012****
coagulation disorder					3100.80	***<0.001*****						
No	24,624	99.46%	48	63.16%			Ref.			Ref.		
Yes	133	0.54%	28	36.84%			108.01	65.10, 176.01	***<0.001*****	114.21	67.90, 190.00	***<0.001*****
uterine fibroids/adenomyosis					0.51	0.917						
No	24,023	97.04%	73	96.05%			-	-	-	-	-	-
Yes	734	2.96%	3	3.95%			-	-	-	-	-	-
polyhydramnios					0.62	0.892						
No	22,299	90.07%	67	88.16%			-	-	-	-	-	-

Yes	2,458	9.93%	9	11.84%			-	-	-	-	-	-
umbilical cord entanglement					0.39	0.943						
No	17,342	70.05%	55	72.37%			-	-	-	-	-	-
Yes	7,415	29.95%	21	27.63%			-	-	-	-	-	-
premature rupture of membranes					39.31	***<0.001*****						
No	19,255	77.78%	43	56.58%			Ref.			Ref.		
Yes	5,502	22.22%	33	43.42%			2.69	1.69, 4.22	***<0.001*****	2.79	1.72, 4.51	***<0.001*****
placental abruption					9.96	***0.019****						
No	24,710	99.81%	75	98.68%			Ref.			Ref.		
Yes	47	0.19%	1	1.32%			7.01	0.39, 32.7	0.056	-	-	-
vaginal bleeding during pregnancy					0.39	0.942						
No	23,503	94.93%	73	96.05%			-	-	-	-	-	-
Yes	1,254	5.07%	3	3.95%			-	-	-	-	-	-
scarred uterus					12.38	***0.006****						
No	24,500	98.96%	73	96.05%			Ref.			Ref.		
Yes	257	1.04%	3	3.95%			3.92	0.96, 10.6	***0.021****	6.[illegible]9	1.48, 21.10	***0.004****
Delivery Process and Neonatal Conditions												

Time of delivery					0.14	0.986						
Day shift	10,374	41.90%	33	43.42%			-	-	-	-	-	-
Night shift	14,383	58.10%	43	56.58%			-	-	-	-	-	-
Total duration of labor					62.15	<0.001**						
normal	24,395	98.54%	69	90.79%			Ref.			Ref.		
prolonged	362	1.46%	7	9.21%			6.84	2.84, 14.0	<0.001**	5.57	2.18, 12.10	<0.001**
First stage of labor - Latent phase					4.59	0.205						
normal	24,337	98.30%	73	96.05%			-	-	-	-	-	-
prolonged	420	1.70%	3	3.95%			-	-	-	-	-	-
First stage of labor - Active phase					8.27	0.041						
normal	24,264	98.01%	72	94.74%			-	-	-	-	-	-
prolonged	493	1.99%	4	5.26%			-	-	-	-	-	-
Second stage of labo					19.57	<0.001**						
normal	24,565	99.22%	73	96.05%			Ref.			Ref.		

prolonged	192	0.78%	3	3.95%			5.26	1.28, 14.3	*0.005**	3.13	0.71, 9.65	0.078
Third stage of labo					0.45	0.930						
normal	24,553	99.18%	75	98.68%			-	-	-	-	-	-
prolonged	204	0.82%	1	1.32%			-	-	-	-	-	-
Placental retention/Placenta accreta/Placental implantation					40.92	*<0.001***						
No	20,721	83.70%	49	64.47%			Ref.			Ref.		
Yes	4,036	16.30%	27	35.53%			2.83	1.74, 4.49	*<0.001***	2.97	1.83, 4.73	*<0.001***
Analgesia during labor					27.45	*<0.001***						
No	23,831	96.26%	67	88.16%			Ref.			Ref.		
Yes	926	3.74%	9	11.84%			3.46	1.60, 6.59	*<0.001***	3.54	1.64, 6.79	*<0.001***
Instrumental assistance in delivery					0.81	0.848						
No	24,153	97.56%	75	98.68%			-	-	-	-	-	-
Yes	604	2.44%	1	1.32%			-	-	-	-	-	-
Lacerations of the cervix,					0.01	0.999						

vagina, or perineum												
No	22,468	90.75%	69	90.79%			-	-	-	-	-	-
Yes	2,289	9.25%	7	9.21%			-	-	-	-	-	-
Newborn weight (grams)					11.83	***0.037****						
<2500	227	0.92%	1	1.32%			Ref.			Ref.		
2500-4000	23,159	93.55%	66	86.84%			0.65	0.14, 11.4	0.666	-	-	
>4000	1,371	5.54%	9	11.84%			1.49	0.28, 27.5	0.706	-	-	-
Newborn length (centimeters)					2.95	0.399						
⩽55	24,036	97.09%	72	94.74%			-	-	-	-	-	-
>55	721	2.91%	4	5.26%			-	-	-	-	-	-