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ORIGINAL RESEARCH

Development and Internal Validation of a Predictive Model for Deep Venous Thrombosis Following Colpocleisis in Elderly Patients with Pelvic Organ Prolapse

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Purpose: Colpocleisis is a surgical option for elderly women with advanced pelvic organ prolapse (POP), often complicated by comorbidities that heighten postoperative deep venous thrombosis (DVT) risk. Effective tools for predicting postoperative DVT in these patients are lacking. This study aimed to develop a predictive model for the risk of DVT following colpocleisis and to validate its performance.

Patients and Methods: This retrospective study included elderly patients who underwent colpocleisis for advanced POP between August 2019 and December 2024. Demographics, obstetric history, comorbidities, preoperative tests, and surgical details were analyzed. The primary endpoint was postoperative DVT, confirmed by ultrasound examination. Univariate and multivariable logistic regression analyses identified risk factors, which informed the development of a predictive nomogram-a graphical tool that translates statistical risk into a user-friendly format for individual prediction. Model performance was assessed using the area under the receiver operating characteristic curve (AUC), calibration curves, and decision curve analysis (DCA), which evaluates the net clinical benefit across threshold probabilities.

Results: Of 307 patients, 8.8% (27/307) developed postoperative DVT. Multivariable analysis identified insulin-dependent diabetes, elevated preoperative cholesterol, and D-dimer levels as independent risk factors. The nomogram demonstrated strong discriminatory ability, with AUCs of 0.809 (95% confidence interval [CI]: 0.760–0.857) in the training set and 0.802 (95% CI: 0.752–0.852) in the validation set. At the optimal threshold (0.494), sensitivity was 0.725, specificity 0.848, positive predictive value (PPV) 0.805, and negative predictive value (NPV) 0.728. Calibration curves showed alignment between predicted and observed outcomes, while DCA demonstrated significant net benefit.

Conclusion: This nomogram is a valuable tool for early DVT risk stratification in elderly colpocleisis patients. External validation in prospective multicenter studies is warranted.

Keywords: colpocleisis, lower extremity venous thrombosis, prolapse, prediction model, risk factors, nomogram

Introduction

Pelvic organ prolapse (POP) is a common disease among females.[1] For frail, elderly patients with moderate to severe POP who do not desire to preserve vaginal sexual function or who have multiple comorbidities, obliterative procedures, such as colpocleisis, are frequently one of the leading options.[2] These procedures have many benefits, including simplicity and shorter operative times, high patient satisfaction, and low recurrence rates.[3,4] However, due to advanced age, high comorbidity rates, and mobility limitations commonly seen in this population with POP, they are at greater

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perioperative risk regarding venous thromboembolism (VTE),[5] which may lead to grave outcomes. This elevated risk deserves greater attention and caution by surgeons.

Another pressing issue is the lack of effective tools to screen and stratify DVT risk following colpocleisis. Although prediction models have been increasingly used in the field of female pelvic floor diseases in recent years,[6–8] there are no models reported on the risk of thrombosis after colpocleisis to date. Common perioperative thromboembolism risk assessment tools, such as the Caprini score, have demonstrated good predictive capability, validated with data from patients across multiple specialties.[9,10] However, due to the unique characteristics of patients undergoing obliterative procedures, this model may struggle to perform its intended function effectively in this patient population. Previous studies have shown that, due to the advanced age and potential multiple comorbidities and prior medical history in this population, Caprini score assessments often place all patients in the "very high risk" category (score above 5), thus diminishing the utility of risk stratification and making it challenging to develop more precise, individualized management strategies.[11] Notably, a significant proportion of DVT in the perioperative setting may be asymptomatic and therefore underdiagnosed. In our previous study involving elderly women undergoing colpocleisis, 15.3% of patients were found to have preoperative lower extremity DVT on routine ultrasound examination, despite most being asymptomatic.[12] If left undetected, these silent events can progress to more severe complications, including pulmonary embolism (PE), post-thrombotic syndrome, and increased morbidity.[13,14] These findings underscore the silent nature of DVT in this population and emphasize the importance of early identification through effective risk prediction tools.

Similar predictive models have shown clinical value in other surgical disciplines, such as gynecologic oncology and urology, where individualized risk stratification has improved perioperative care and outcomes.[15,16] Therefore, our study aims to establish a prediction model to assess postoperative DVT risk in this patient population, internally cross-validated to evaluate the predictive performance of the model.

Materials and Methods

Study Cohort

We collected data from patients who underwent colpocleisis for moderate to severe POP at a tertiary university-affiliated hospital's pelvic floor center between August 2019 and December 2024. The inclusion criteria were as follows: (1) prolapse of any compartment with a grade of II or higher according to the pelvic organ prolapse quantification (POP-Q) classification; (2) age ≥60 years, with no desire to preserve vaginal sexual function; and (3) complete medical records. The exclusion criteria were: (1) preoperative diagnosis of DVT; (2) severe hematologic diseases or other conditions potentially causing significant coagulopathy; and (3) patients on long-term anticoagulation therapy for chronic conditions (eg, atrial fibrillation, post-cardiac valve replacement, history of thrombosis, post-stroke). This study was conducted in full accordance with the principles of the Declaration of Helsinki. Prior to surgery, patients and their families were provided with a detailed explanation, including potential impacts on sexual function, and signed informed consent forms. The study protocol was approved by the ethics committee of the institution.

All patients underwent Lefort colpocleisis or modified total colpocleisis after completing perioperative preparation, with detailed surgical procedures documented in previous literature.[17,18] Based on the high risk of DVT determined by the Caprini score, all patients, unless contraindicated, received subcutaneous injections of 5000 units of low molecular weight heparin (LMWH) daily starting 24 hours postoperatively, along with twice-daily intermittent pneumatic compression therapy.

Clinical Characteristics

The data in this study were obtained from patients' hospitalization electronic medical records (EMRs), covering basic demographic information, obstetric history, comorbidities and medical history, preoperative ancillary test results, and perioperative data. Basic information included age, body mass index (BMI), and smoking history. Obstetric history encompassed the number of pregnancies and births, and menopausal duration. Comorbidities and past medical history included hypertension, diabetes, insulin-dependent diabetes, ischemic heart disease, lower limb varicose veins, anemia, history of VTE, and current or past malignancies. Preoperative ancillary test results included triglycerides, cholesterol,

and coagulation function tests—activated partial thromboplastin time (APTT), prothrombin time (PT), thrombin time (TT), fibrinogen (Fib), and D-dimer. A preoperative lower limb compression ultrasound examination is required to exclude the possibility of existing DVT. Perioperative data included the type of surgery, concomitant hysterectomy, duration of surgery, estimated blood loss, changes in hemoglobin and hematocrit at preoperative and 24-hour postoperative intervals, postoperative use of LMWH, and duration of postoperative hospital stay.

Diagnosis of DVT

The diagnosis of DVT was obtained by experienced sonographers using standardized bilateral lower limb compression ultrasonography (GE Voluson S8 Pro 12L-RS, 5.0–12.0 MHz). This examination was typically performed preoperatively and within seven days postoperatively to collect relevant diagnostic data on DVT.

Identification of DVT Risk Factors, Model Development, and Internal Validation

The first step involved data cleaning, during which the accuracy and completeness of the extracted data were reassessed and compiled into a standardized dataset. Patients with incomplete medical records were excluded at this stage. Because of the relatively low incidence of postoperative DVT, the dataset had a class imbalance problem. To address this, we applied the Synthetic Minority Over-sampling Technique (SMOTE) to the entire dataset prior to model construction. This oversampling was conducted before cross-validation to balance the class distribution between DVT and non-DVT cases.

Then, univariate analysis was carried out to preliminarily estimate potential DVT risks factors, variables with a P-value below 0.05 were selected for the multivariable logistic regression analysis to finally determine the independent risk factors for DVT following colpocleisis. Based on the multivariable analysis, the independent risk factors identified are incorporated into the final logistic regression risk prediction model, which is visualized using a nomogram.

Stratified 10-fold cross-validation was performed on the SMOTE-balanced dataset to ensure proportional representation of the outcome across folds. The model is presented with several common metrics: the area under the receiver operating characteristic curve (AUC), the calibration curve, and decision curve analysis (DCA). Besides that, the best threshold of the model was explored, along with sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). The AUC reflects the model's discriminative power: values closer to 1 imply higher discrimination capabilities, while those closer to 0.5 mean poor discrimination, almost comparable to random chance. The Youden index, which is calculated as sensitivity + specificity - 1, helps in finding the optimal threshold of the model. The threshold where the Youden index is maximized is considered as an optimal cut-off, and PPV and NPV are then calculated to reflect the model's accuracy of identifying true positives and true negatives.

The calibration curve assesses the model's calibration ability; the closer this curve is to a 45-degree line, the better the agreement between predicted and observed values. Additionally, the model's calibration ability is evaluated using the Hosmer-Lemeshow test, with P-values greater than 0.05 indicating a good fit between observed and predicted outcomes. The DCA curve quantifies the net benefit at different thresholds, helping to evaluate the practical application value of the model in clinical decision-making.

Statistics Analysis

The statistical analysis, model construction, and evaluation in this study were conducted using R software (version 4.3.0) and its associated packages. Categorical data are presented as frequencies and percentages, with comparisons between groups made using Pearson's chi-square test or Fisher's exact test as appropriate. For continuous data, the Kolmogorov–Smirnov test was first used to assess normality. Data following a normal distribution are expressed as mean ± standard deviation and compared using Student's *t*-test. Data not following a normal distribution are presented as median and range, with the Mann–Whitney *U*-test used for comparison. A two-tailed P-value < 0.05 was considered statistically significant.

Results

In total, 409 patients underwent colpocleisis during the study period, and 102 were excluded for the following reasons: 56 were diagnosed with lower extremity DVT in preoperative examinations, 28 had incomplete perioperative data, and

18 were undergoing long-term anticoagulant therapy. The detailed flowchart is shown in Figure 1. Finally, 307 patients were included, with 27 cases of postoperative DVT (8.8%). The mean age of these patients was 69.67 ± 6.16 years, and the mean BMI was 24.14±2.80 kg/m². More than 92.8% (285/307) had two or more comorbidities. Detailed baseline and clinical data are presented in Table 1

Univariate and Multivariable Analysis

The univariate analysis revealed that, compared to the non-DVT group, the DVT group had a higher proportion of patients with insulin-dependent diabetes and elevated preoperative cholesterol and D-dimer levels, with statistically significant differences ($P < 0.05$). No significant differences were observed between the two groups for other variables, details are shown in Table 1.

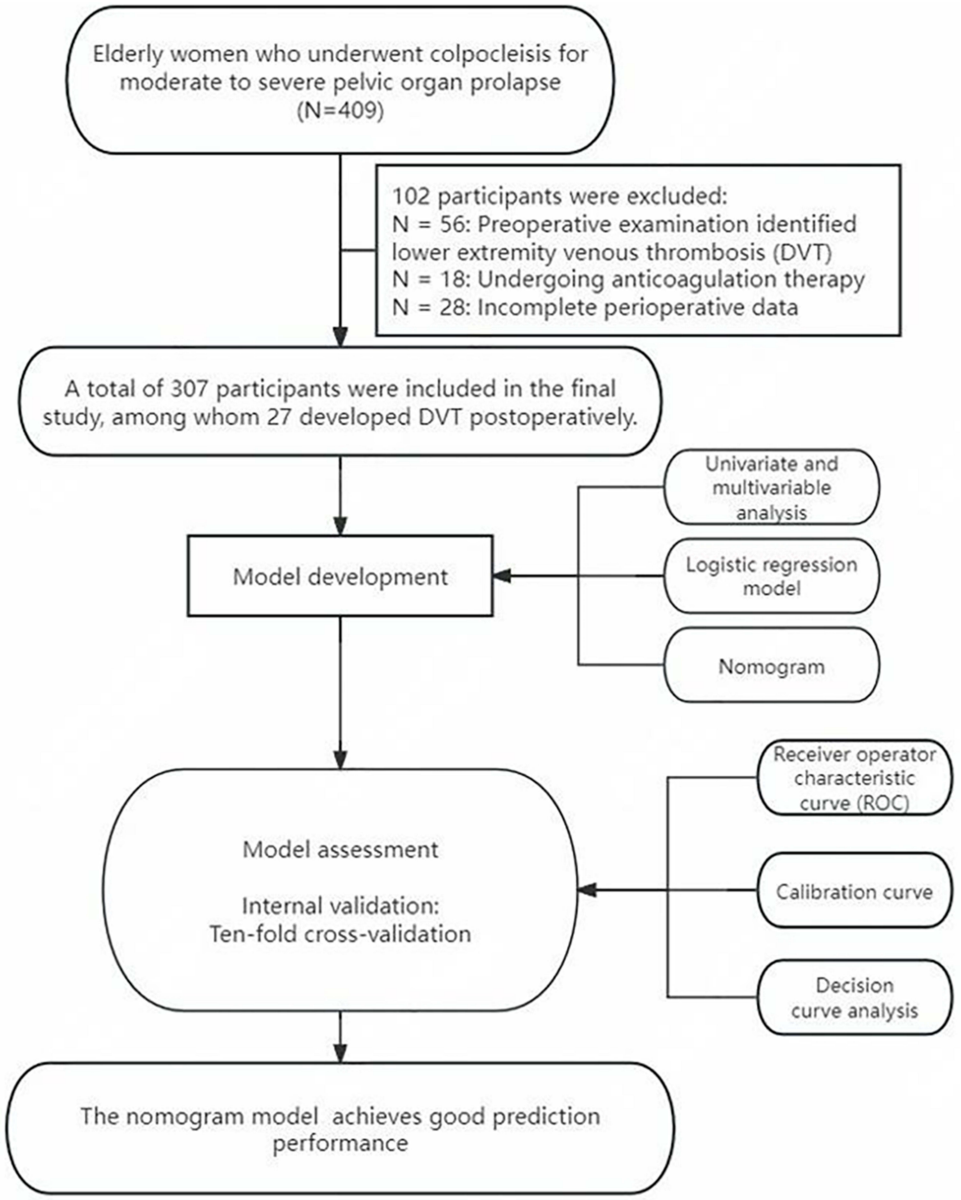

Figure 1 Flow chart of the study design.
Abbreviations: DVT, deep venous thrombosis; ROC, receiver operating characteristic curve.

Table 1 Demographic and Clinical Characteristics of the Lower Extremity Deep Venous Thrombosis (DVT) Group and the Non-DVT Group

	Total	Non-DVT Group	DVT Group	t/x^2	P value
	(n=307)	(n=280)	(n=27)		
Age (years), mean±SD	69.67±6.16	69.51±5.94	71.33±8.03	−1.472	0.142
BMI (kg/m^2), mean±SD	24.14±2.80	24.12±2.75	24.35±3.25	−0.414	0.679
Gravidity, mean±SD	3.65±1.54	3.63±1.53	3.85±1.61	−0.708	0.479
Parity, mean±SD	2.78±1.38	2.76±1.38	2.89±1.40	−0.447	0.655
Duration of menopause (years), mean±SD	19.15±7.87	19.00±7.96	20.70±6.74	−1.075	0.283
Hypertension, n(%)	203(66.1)	183(65.3)	20(74.0)	0.835	0.361
Diabetes, n(%)	100(32.5)	90(32.1)	10(37.0)	0.269	0.604
Diabetes requires insulin treatment, n(%)	27(8.7)	18(6.4)	9(33.3)	22.223	<0.001
Ischemic heart disease, n(%)	65(21.1)	61(21.8)	4(14.8)	0.717	0.397
Varicose vein, n(%)	14(5.0)	12(4.3)	2(7.4)	NA	0.354
Anemia, n(%)	21(6.8)	19(6.7)	2(7.4)	NA	0.706
History of VTE, n(%)	7(2.2)	5(1.7)	2(7.4)	NA	0.119
Current or past malignancies, n(%)	10(3.2)	8(2.8)	2(7.4)	NA	0.216
Smoking, n(%)	8(2.6)	6(2.1)	2(7.4)	NA	0.150
Triglycerides (mmol/l), median (range)	1.52(0.54–9.91)	1.53(0.54–9.91)	1.37(0.66–2.53)	NA	0.279
Cholesterol (mmol/l), mean±SD	5.12±1.07	5.05±1.03	5.81±1.23	−3.567	<0.001
PT (s), mean±SD	11.10±0.76	11.09±0.76	11.16±0.84	−0.453	0.651
APTT (s), mean±SD	26.34±2.90	26.33±2.97	26.53±2.02	−0.354	0.723
TT (s), mean±SD	16.98±0.89	16.98±0.88	17.01±0.92	−0.215	0.830
Fib (g/l), mean±SD	3.11±0.80	3.12±0.81	2.99±0.69	0.855	0.393
D-Dimer (mg/l), median (range)	0.29(0.04–3.76)	0.28(0.04–3.76)	0.56(0.09–3.29)	NA	<0.001
Surgical methods, n(%)				NA	0.778
Modified total colpocleisis	262(85.4)	238(85.0)	24(88.8)		
LeFort colpocleisis	45(14.6)	42(15.0)	3(11.2)		
Concomitant hysterectomy, n(%)				0.164	0.685
With hysterectomy	237(77.2)	217(77.5)	20(74.0)		
Without hysterectomy	70(22.8)	63(22.5)	7(26.0)		
Duration of surgery (min), mean±SD	106.63±39.75	107.41±40.30	98.44±33.00	1.120	0.263
Estimated blood loss (mL), median (range)	30(5–300)	30(5–300)	20(5–100)	NA	0.380
Δ Hemoglobin level (g/l), mean±SD	11.16±10.37	11.33±10.63	9.37±7.09	1.304	0.200
Δ Hematocrit (%), mean±SD	3.57±3.14	3.62±3.20	3.04±2.44	0.918	0.359
Postoperative heparin anticoagulation, n(%)				NA	0.278
Postoperative anticoagulation within 24h	206(67.1)	184(65.7)	22(81.5)		
Postoperative anticoagulation after 24h	91(29.6)	86(30.7)	5(18.5)		
No pharmacological anticoagulation	10(3.3)	10(3.6)	0(0.0)		
Duration of postoperative stay (days), mean±SD	6.04±1.86	6.05±1.91	5.89±1.22	0.438	0.662

Note: ΔHemoglobin level and ΔHematocrit refer to the differences between the Hemoglobin level and Hematocrit values at 24 hours postoperatively and their corresponding preoperative test values, respectively.

Abbreviations: SD, standard deviation; BMI, body mass index; VTE, venous thromboembolism; NA, not available; PT, prothrombin time; APTT, activated partial thromboplastin time; TT, thrombin time; Fib, fbrinogen.

Further multivariable logistic regression analysis confirmed the following variables as independent risk factors for postoperative DVT after colpocleisis: insulin-dependent diabetes (odds ratio [OR] = 7.034, 95% confidence interval [CI] = 2.552–19.390, P < 0.001), preoperative cholesterol (OR = 1.849, 95% CI = 1.241–2.755, P = 0.003), and D-dimer levels (OR = 2.962, 95% CI = 1.589–5.521, P = 0.001). Detailed results are presented in Table 2.

Table 2 Multivariable Logistic Regression Analysis of Factors Associated with Lower Extremity Deep Venous Thrombosis

	B	SE	Wald	P value	OR (95% CI)
Diabetes requires insulin treatment	1.951	0.517	14.216	<0.001	7.034(2.552–19.390)
Cholesterol	0.615	0.203	9.124	0.003	1.849(1.241–2.755)
D-Dimer	1.086	0.318	11.685	0.001	2.962(1.589–5.521)

Abbreviations: SE, standard error; OR, odds ratio; CI, confidence interval; VTE, venous thromboembolism.

Development and Validation of Nomogram Model

Based on the above analysis, a risk prediction model for postoperative DVT following colpocleisis was constructed using logistic regression and visualized as a nomogram (Figure 2).

The predictive performance of the model was evaluated with 10-fold internal cross-validation. The AUC for the training and validation sets was 0.809 (95% CI: 0.760–0.857) and 0.802 (95% CI: 0.752–0.852) respectively (Figure 3A and B). From the Youden index, the model threshold was 0.494 with a sensitivity of 0.725, specificity of 0.848, PPV of 0.805 and NPV of 0.728. The calibration curves showed a good agreement between the predicted and observed values in both training and validation sets (Figure 4A and B). Consistently, the Hosmer-Lemeshow test yielded P-values of 0.311 and 0.341 for the training and validation sets, respectively, indicating no significant difference between the predicted and observed values. The DCA curves for the training and validation sets (Figure 5A and B) showed that the predictive model using threshold of 0.494 gave a high net benefit, indicating favorable clinical applicability.

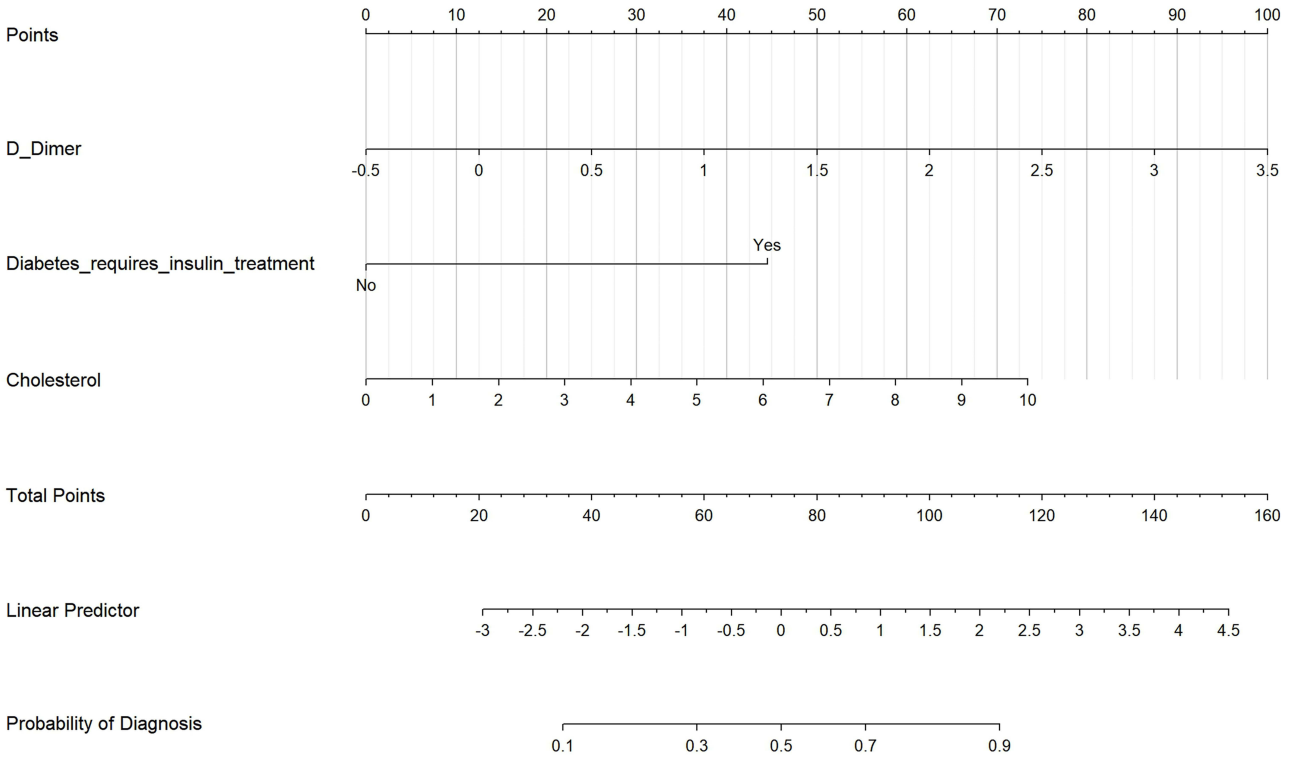

Figure 2 The nomogram for predict the risk of DVT following colpocleisis. Each variable is assigned a specific score based on its value along the variable axis. The individual scores are then totaled to provide an overall score, which corresponds to the estimated risk of DVT.

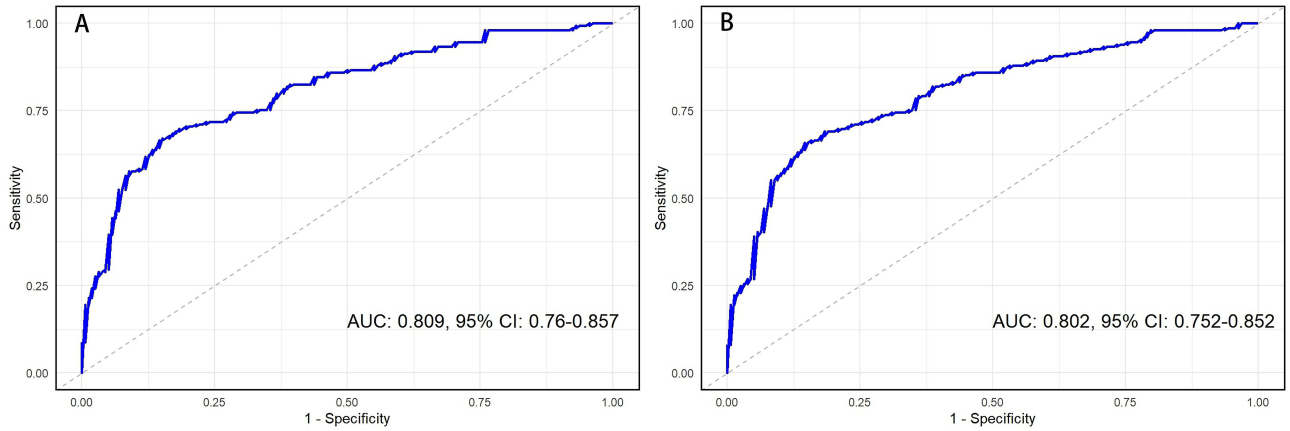

Figure 3 The receiver operating characteristic curve of predictive model in the training set (**A**), the internal validation (**B**).
Abbreviations: AUC, area under the receiver operating characteristic curve; CI, confidence interval.

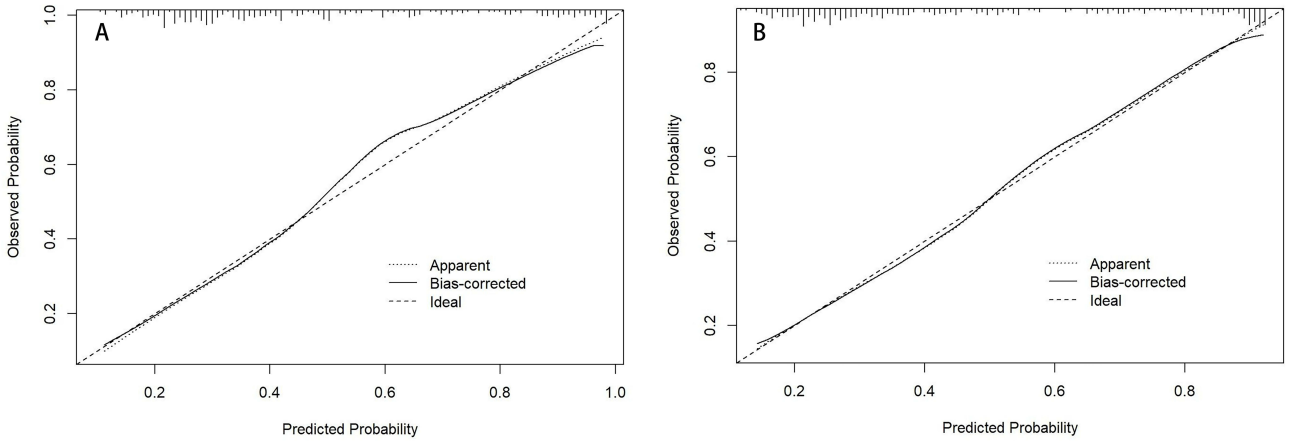

Figure 4 The calibration curve of predictive model in the training set (**A**), the internal validation (**B**). The Hosmer-Lemeshow test showed P-values of 0.311 and 0.341 for the training and validation sets, respectively.

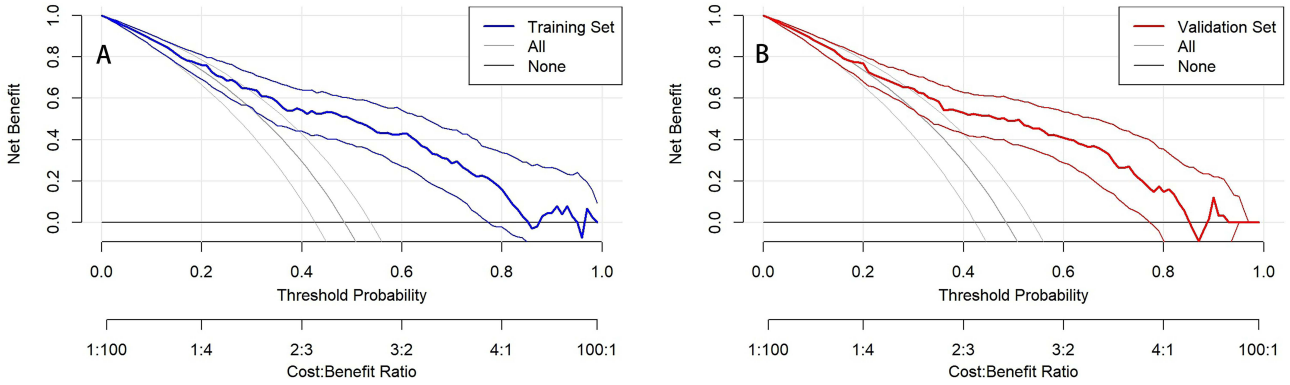

Figure 5 The decision curve analysis of predictive model in the training set (**A**), the internal validation (**B**).

Discussion

To the best of our knowledge, this represents the first attempt to establish a predictive model specifically for the assessment of postoperative DVT risk in elderly patients with POP undergoing colpocleisis. Our model is based on a specialized disease-specific cohort containing a substantial number of cases rather than from a large-scale

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comprehensive database. By analyzing a range of clinical and laboratory data, we identified a number of independent risk factors and constructed a nomogram predictive model using logistic regression. Internal validation demonstrated the model's robust predictive performance and potential clinical utility.

Moreover, our study revealed that the incidence of postoperative DVT might be higher than previously anticipated, reaching 8.8%. This finding highlights the need for heightened vigilance among surgeons regarding the risk of post-operative DVT after colpocleisis. A previous study using data from the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) reported a DVT incidence of 1.2% (3 out of 245 cases).[19] This finding differs markedly from our results. A possible reason for this discrepancy is that prior studies relied on data mining from the ACS-NSQIP database, which does not include details on perioperative DVT screening protocols. According to previous research, most DVT cases are asymptomatic and may go undetected.[20] In contrast, our study was based on a specialized cohort with stricter diagnostic criteria, enabling a more precise evaluation of postoperative DVT incidence.

The low incidence of postoperative DVT reported in previous studies on colpocleisis has resulted in a lack of guidelines or consensus on its risk factors. Referring to prior research on DVT after gynecological surgery,[21,22] we included a range of relevant clinical and laboratory variables. Multivariable logistic regression analysis revealed that insulin-dependent diabetes, preoperative cholesterol and D-dimer levels were independently associated with the occurrence of DVT after colpocleisis. This finding also tallies with the earlier research on DVT risk factors subsequent to gynecological procedures.[23,24]

Interestingly, several factors traditionally considered high risk for postoperative thrombosis, such as advanced age, postmenopausal status, BMI, and operative duration, did not show a significant association with DVT following colpocleisis. This may be due to the relatively homogeneous characteristics of our study population, as all participants were elderly women with a narrow distribution in these variables, potentially limiting their discriminatory power in statistical analyses.

Ultimately, we included insulin-dependent diabetes, preoperative cholesterol levels, and D-dimer in the predictive model. These variables are routinely recorded in electronic medical records, making the model both practical and easily applicable in clinical settings. Detailed performance evaluation by 10-fold cross-validation yielded AUCs of 0.809 and 0.802 for the training and validation sets, respectively. This demonstrated strong discriminatory power. Calibration curves and the Hosmer-Lemeshow test further confirmed the high concordance between the predicted and observed values highlight the model's reliability. Moreover, based on the Youden index, the optimal threshold of the model was derived as 0.494, and therefore it is more applicable in clinical practice. The sensitivity at this cutoff reached 0.725, specificity was 0.848, PPV was 0.805, while NPV was 0.728, reflecting a robust predictive performance of the model. DCA further confirmed that at this threshold, the model had high net benefit, which may suggest a potential utility as a initial DVT screening tool after colpocleisis. This model could assist clinicians in identifying high-risk patients and serve as an important reference for further diagnostic studies, including lower extremity compression ultrasound.

We recognize several limitations in the present study. First, this is a retrospective study, and there may be inherent biases in the results despite our strict inclusion and exclusion criteria. Second, this is a single-center study, and the patients all belonged to the elderly Han Chinese female population. Although the model performed well in internal validation, the limitations in geographic and ethnic diversity cast doubt on its generalizability. Third, while the overall sample size was sufficient, the cases with a few specific comorbidities were relatively few, thus making it hard to detect such factors' significant impact. Fourth, although the final model included only three predictors, the number of DVT events (n = 27) yields an event-per-variable (EPV) ratio of 9. Therefore, there remains a potential risk of overfitting, and the model's generalizability may be limited and should be interpreted with caution. Last but not least, in consideration of its clinical practicality, we have merely included those predictors easily accessible in routine practice; hence, we exclude new thrombotic markers like thrombomodulin (TM) and thrombin-antithrombin complex (TAT), which might reduce the predictive power of this model. In the light of such limitations, Future studies should aim to externally validate the model using multi-center and multi-regional prospective cohorts with larger sample sizes and more diverse demographic and ethnic backgrounds, thereby enhancing its generalizability and adaptability across broader clinical settings. Furthermore, incorporating novel thrombotic biomarkers in these validation cohorts may help further refine and improve the model's predictive accuracy.

Conclusion

This study developed a preliminary nomogram prediction model based on readily accessible clinical variables. In internal validation, the model showed promising discrimination and calibration performance. While it may serve as a potentially useful tool for early risk stratification and individualized risk management of postoperative DVT, its generalizability and clinical applicability remain to be established. Further prospective, multicenter studies with larger and more diverse populations are needed to validate and refine the model before clinical implementation.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work the authors used ChatGPT-4o in order to improve the readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Abbreviations

POP, pelvic organ prolapse; DVT, deep venous thrombosis; AUC, the area under the receiver operating characteristic curve; DCA, decision curve analysis; PPV, positive predictive value; NPV, negative predictive value; VTE, venous thromboembolism; POP-Q, pelvic organ prolapse quantification; LMWH, low molecular weight heparin; EMRs, electronic medical records; BMI, body mass index; APTT, activated partial thromboplastin time; PT, prothrombin time; TT, thrombin time; Fib, fibrinogen; ACS-NSQIP, the American College of Surgeons National Surgical Quality Improvement Program; oxLDL, oxidized low-density lipoprotein; TM, thrombomodulin; TAT, thrombin-antithrombin complex.

Data Sharing Statement

The data of this study are available from either of the corresponding authors, Dr. Chaoqin Lin or Dr. Xiaoxiang Jiang, upon reasonable request.

Ethics Approval and Consent to Participate

Ethical approval was granted by the Ethical Review Committee of Fujian Maternity and Child Health Hospital (2024KY105). All participants provided written informed consent prior to their inclusion in the survey.

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Disclosure

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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