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ORIGINAL ARTICLE

Nomogram for predicting venous thromboembolism after spinal surgery

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Abstract

Purpose This study aimed to establish a nomogram to predict the risk of venous thromboembolism (VTE), identifying potential risk factors, and providing theoretical basis for prevention of VTE after spinal surgery.

Methods A retrospective analysis was conducted on 2754 patients who underwent spinal surgery. The general characteristics of the training group were initially screened using univariate logistic analysis, and the LASSO method was used for optimal prediction. Subsequently, multivariate logistic regression analysis was performed to identify independent risk factors for postoperative VTE in the training group, and a nomogram for predict risk of VTE was established. The discrimination, calibration, and clinical usefulness of the nomogram were separately evaluated using the C-index, receiver operating characteristic curve, calibration plot and clinical decision curve, and was validated using data from the validation group finally.

Results Multivariate logistic regression analysis identified 10 independent risk factors for VTE after spinal surgery. A nomogram was established based on these independent risk factors. The C-index for the training and validation groups indicating high accuracy and stability of the model. The area under the receiver operating characteristic curve indicating excellent discrimination ability; the calibration curves showed outstanding calibration for both the training and validation groups. Decision curve analysis showed the clinical net benefit of using the nomogram could be maximized in the probability threshold range of 0.01–1.

Conclusion Patients undergoing spinal surgery with elevated D-dimer levels, prolonger surgical, and cervical surgery have higher risk of VTE. The nomogram can provide a theoretical basis for clinicians to prevent VTE.

Keywords Spinal surgery · Venous thromboembolism · Deep vein thrombosis · Pulmonary embolism · Nomogram

Introduction

Venous thromboembolism (VTE) is one of the five most common blood vessel diseases [1], and is a common complication after surgery with an incidence rate ranging from 0.2 to 31.2% [2], including two stages of deep vein thrombosis (DVT) and pulmonary embolism (PE). DVT is more commonly seen in the lower extremities and often presents with swelling, pain, purplish-red skin coloration, elevated skin temperature, superficial vein dilation, and can even lead to disability in severe cases. The clinical presentation of PE depends on the extent and speed of vessel obstruction and the cardiopulmonary functional status. Mild cases may be asymptomatic, while severe cases may present with sudden onset of dyspnea, chest pain, hemoptysis, and even shock or death. Orthopedic patients are at high risk for VTE due to factors, such as surgical trauma, cast

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immobilization, long recovery time, and medication use. The incidence of VTE after spinal surgery ranges from 0.2 to 13.6% [3], and rates of pulmonary embolism range from 0.03 to 2.4% [4–6], and the mortality rate was as high as 0.34% [7]. It also prolongs the patient's hospitalization time and brings enormous economic and social burden, and has become an important public health problem. Therefore, the prevention of VTE after spinal surgery is of great significance in accelerating the recovery of spinal patients, reducing complications, and lowering the medical burden.

The nomogram is one of the most commonly used statistical methods in clinical prediction models. It not only has advantages such as simplicity, intuitiveness, and easy to operate, but also can visualize abstract and complex regression equations, making it more convenient to calculate the probability of risk factors. The nomogram has been proven to be more reliable than other systems and has therefore been recommended as a replacement or even a new standard [8, 9]. The nomogram can help clinicians to vividly show the patients their risk of developing VTE, improving patient compliance. Additionally, it can guide doctors, nurses, and management staff to perform early diagnosis, early prevention, and early intervention of postoperative VTE, providing a theoretical basis for the perioperative management of spinal surgery patients [10]. Therefore, in this study, a clinical prediction model using nomogram was established to explore the independent risk factors for VTE after spinal surgery, and a risk assessment model was constructed to identify patients at risk of VTE after spinal surgery at an early stage, to manage these patients accurately and to allocate medical resources effectively.

Patients and methods

Study population and experimental design

We conducted a retrospective analysis of a patient cohort who underwent surgical treatment in the Department of Spinal Surgery at Qingdao University Affiliated Hospital from January 2015 to December 2020. Inclusion criteria: (1) Age ≥ 18 years; (2) Received spinal surgery treatment; (3) Postoperative hospital stay > 72 h; (4) Complete case information with sufficient data. Exclusion criteria: To be excluded if having any of the following: (1) Percutaneous vertebroplasty, nerve root blockade, microdiscectomy; (2) Combined pelvic or lower limb fractures; (3) Surgery within 3 months; (4) Preoperative diagnosis of lower limb DVT by lower limb vascular ultrasound; (5) PE diagnosed by CT pulmonary angiography before surgery; (6) History of thrombosis; (7) Comorbid with blood system diseases or long-term use of anticoagulants; (8) Missing or incomplete medical records. This study was approved by the institutional ethics committee, and informed consent was obtained from each patient.

Clinical outcomes and definitions

We defined the occurrence of lower limb DVT as the clinical outcome. Venous ultrasound is the gold standard for determining whether lower limb DVT has formed [11]. According to the protocol for lower limb vascular ultrasound examination, the filling state of the blood flow in each vein lumen and the presence or absence of thrombosis were determined [12]. If a thrombus was present, its location was recorded. Patients who did not undergo lower limb venous ultrasound examination during hospitalization were excluded from the analysis in this study.

Selection of predictors

Demographic characteristics included gender, age, body mass index (BMI), hypertension, diabetes, previous surgery (pre_surgery), bed > 3 days, smoke, drinking, cancer, and trauma. Laboratory examinations included white blood cell count (WBC), platelet count (PLT), hemoglobin (Hb), triglyceride (TG), serum total cholesterol (TC), D-dimer, prothrombin time (PT), thrombin time (TT), and activated partial thromboplastin time (APTT). Surgical indicators included location (cervical, thoracolumbar), duration, and blood loss. The above information was obtained from the electronic medical record.

Statistical analysis

A total of 2754 postoperative spinal patients was randomly divided into training and validation groups with a ratio of 7:3 using SPSS 22.0 software (SPSS Inc., Chicago, Illinois, USA). Continuous variables were described as mean ± standard deviation, while categorical variables were described as proportions. Statistical differences between means and proportions were confirmed using Student's t-test (for continuous variables) and Chi-Square Test (for categorical variables).

To determine the risk factors for VTE, we initially conducted univariate logistic regression analysis on training group to perform a preliminary screening of factors; subsequently, LASSO regression was also used to reduce high-dimensional data and identify the best predictive features and variables for VTE after spinal surgery [13], Variables with P values less than 0.05 were included in the multivariate logistic regression model to screen for independent risk factors. Finally, the “rms” and “regplot” packages from R software version 4.3.2 (R Foundation for Statistical Computing, Vienna, Austria) were used to visualize the results of the logistic regression analysis, creating a dynamic interactive nomogram; the accuracy, stability, discriminative ability and calibration of the model were evaluated by consistency index (C-index), receiver operating characteristic (ROC) curve, Hosmer–Lemeshow goodness-of-fit test and calibration curve for training group and verification group [14]. The clinical usefulness of the VTE nomogram was determined by quantifying the net benefit at different threshold probabilities in the spinal surgery cohort [15]. Except for individual labeling, all the definitions were statistically significant ($P < 0.05$).

Results

Clinical characteristics and univariate correlations with thrombosis-related risk factors

We collected data from 2754 patients who received surgical treatment for spinal disorders at Qingdao University Affiliated Hospital from January 2015 to December 2020. Among them, 144 patients (7.4%) developed DVT, including 43 cases in the left lower extremity, 49 cases in the right lower extremity, 52 cases in both lower extremities, and 3 cases of PE, all of which were accompanied by DVT in the lower extremities. Among the VTE patients, the highest number of VTE cases occurred after thoracolumbar surgery, accounting for 106 cases (73.6%), while cervical spine surgery accounted for 38 cases (26.4%). The average operation duration for VTE patients was 189.31 ± 90.461 min, and the amount of bleeding was 459.44 ± 462.723 mL (Table 1).

Risk factors associated with VTE

In the univariate logistic analysis, there were significant differences ($P < 0.05$) between the two groups of patients in terms of age, hypertension, diabetes, pre_surgery, bed, smoking, drinking, cancer, trauma, WBC, Hb, TC, D_dimer, PT, APTT, location, duration, and bloodloss(Fig. 1A). LASSO regression was used to further eliminate overfitting and identified 17 risk factors (Fig. 2). Subsequently, these 17 indicators were included in the multivariate logistic analysis, which showed that age, hypertension, bed, drinking, trauma, TC, D_dimer, location, duration, and bloodloss were independent risk factors for postoperative VTE in spinal surgery (Fig. 1B).

Establishment of a dynamic interactive nomogram

A dynamic interactive nomogram was established based on the 10 independent risk factors obtained from multiple logistic regression, which predicts the risk of postoperative VTE in spine surgery. As shown in Fig. 3, The 89th patient in the training group was selected as the subject for the present dynamic interactive predictive model. This patient was 80 years old, had a history of hypertension and bed rest > 3 days, no history of drinking or trauma, TC < 5.17, and D_Dimer > 3000 μg/L. underwent surgery in the thoraclumbar spine, with a surgical duration of 125 min and bloodloss of 1000 mL, and developed VTE after surgery. Moreover, the patient experienced VTE after the spinal surgery. According to this predictive model, the total score for this patient was 8.0, corresponding to a probability of 0.878 for postoperative VTE, which indicated an extremely high risk of VTE for this patient, consistent with the patient's outcome.

Validation of the dynamic interactive nomogram

The C-index for the training and validation groups were 0.94 (95% CI: 0.9204–0.9596) and 0.955 (95% CI: 0.9354–0.9746) respectively, indicating high accuracy and stability of the prediction model. The ROC curves were plotted in the training and validation groups, and the area under the ROC curve (AUC) was calculated to determine the discrimination of the predictive model. The AUC for the training group was 0.940, and the AUC for the validation group was 0.942, indicating a high discrimination of the predictive model [17]. Additionally, the ROC curve in the training group showed a cutoff point of 0.085, indicating that patients with a calculated VTE risk probability greater than 0.085 in the predictive model should receive corresponding clinical interventions to reduce the risk of VTE after spinal surgery (Fig. 4A, B). The Hosmer–Lemeshow goodness-of-fit test (training group: Chi-square = 9.601285, P-value = 0.3837164; validation group: Chi-square = 6.942186, P-value = 0.6431388) and calibration curves demonstrated good calibration of the model in both the training and validation groups (Fig. 4C, D).

Clinical application

The decision curve analysis(DCA) was carried out to evaluate the clinical implications of the prediction model. The DCA for the preoperative VTE progression nomogram is illustrated in Fig. 5. The DCA demonstrated that within the threshold probability range of 0.01–1, the DCA of the predictive model constructed in this study had a higher net benefit than the two ineffective curves, indicating that the use of the VTE nomogram in clinical practice to predict the risk of VTE after spinal surgery and take necessary preventive measures can effectively reduce the risk of postoperative VTE occurrence.

Table 1 Patient characteristics and univariate correlations with thrombosis-related risk factors

Risk factor	VTE ($n=144$)	Non-VTE ($n=1786$)	Statistics	*P* value
Sex [*n*(%)]			1.394	0.238
Male	75 (52.1)	839 (47.0)		
Female	69 (47.9)	947 (53.0)		
Age ($\bar{x} \pm s, y$)	64.76 ± 10.77	57.44 ± 14.79	– 5.811	< 0.001
BMI (kg/m^2)[*n*(%)]			0.802	0.371
> 28	27 (18.8)	392 (21.9)		
≤ 28	117 (81.2)	1394 (78.1)		
Hypertension [*n*(%)]	61 (42.4)	395 (22.1)	30.266	< 0.001
Diabetes [*n*(%)]	28 (19.4)	185 (10.4)	11.205	0.001
Pre_surgery [*n*(%)]	71 (49.3)	628 (35.2)	11.539	0.001
Bed [*n*(%)]	42 (29.2)	204 (11.4)	37.727	< 0.001
Smoke [*n*(%)]	31 (21.5)	240 (13.4)	7.226	0.007
Drinking [*n*(%)]	28 (19.4)	223 (12.5)	5.703	0.017
Cancer [*n*(%)]	21 (14.6)	65 (3.5)	37.488	< 0.001
Trauma [*n*(%)]	53 (36.8)	281 (15.7)	41.346	< 0.001
WBC [*n*(%)]			25.282	< 0.001
> 10 × 10^9/L	65 (45.1)	460 (25.8)		
≤ 10 × 10^9/L	79 (54.9)	1326 (74.2)		
PLT [*n*(%)]			3.762	0.055
> 300 × 10^9/L	17 (11.8)	131 (7.3)		
≤ 300 × 10^9/L	127 (88.2)	1655 (92.7)		
Hb [*n*(%)]			7.225	0.007
< 110 g/L	65 (45.1)	608 (34.0)		
≥ 110 g/L	79 (54.9)	1178 (66.0)		
TG [*n*(%)]			1.240	0.267
> 2.26 mmol/L	14 (9.7)	231 (12.9)		
≤ 2.26 mmol/L	130 (90.3)	1555 (87.1)		
TC [*n*(%)]			126.525	< 0.001
> 5.17 mmol/L	50 (34.7)	123 (6.9)		
≤ 5.17 mmol/L	94 (65.3)	1663 (93.1)		
D_Dimer [*n*(%)]			265.526	< 0.001
< 1000 μg/L	48 (33.3)	1520 (85.1)		
1000–3000 μg/L	54 (37.5)	198 (11.1)		
> 3000 μg/L	42 (29.2)	68 (3.8)		
PT [*n*(%)]			38.204	< 0.001*
> 15 s	4 (2.8)	1 (0.05)		
≤ 15 s	140 (97.2)	1785 (99.95)		
TT [*n*(%)]			0.080	0.778
> 18 s	32 (22.2)	379 (21.2)		
≤ 18 s	112 (77.8)	1407 (78.8)		
APTT [*n*(%)]			7.386	0.007
> 37 s	13 (9.0)	74 (4.1)		
≤ 37 s	131 (91.0)	1712 (95.9)		
Location [*n*(%)]			10.966	0.001
Cervical	38 (26.4)	281 (15.7)		
Thoracolumbar	106 (73.6)	1505 (84.3)		
Duration ($\bar{x} \pm s, min$)	189.31 ± 90.461	120.61 ± 49.360	– 14.823	< 0.001
Bloodloss ($\bar{x} \pm s, ml$)	459.44 ± 462.723	182.54 ± 198.285	– 13.980	< 0.001

*Comparison among groups using Fisher's exact probability test

BMI body mass index, *Pre_surgery* previous surgery, *WBC* white blood cell count, *PLT* platelet, *Hb* hemoglobin, *TG* triglyceride, *TC* total cholesterol, *PT* prothrombin time, *TT* thrombin time, *APTT* activated

Table 1 (continued) partial thromboplastin time

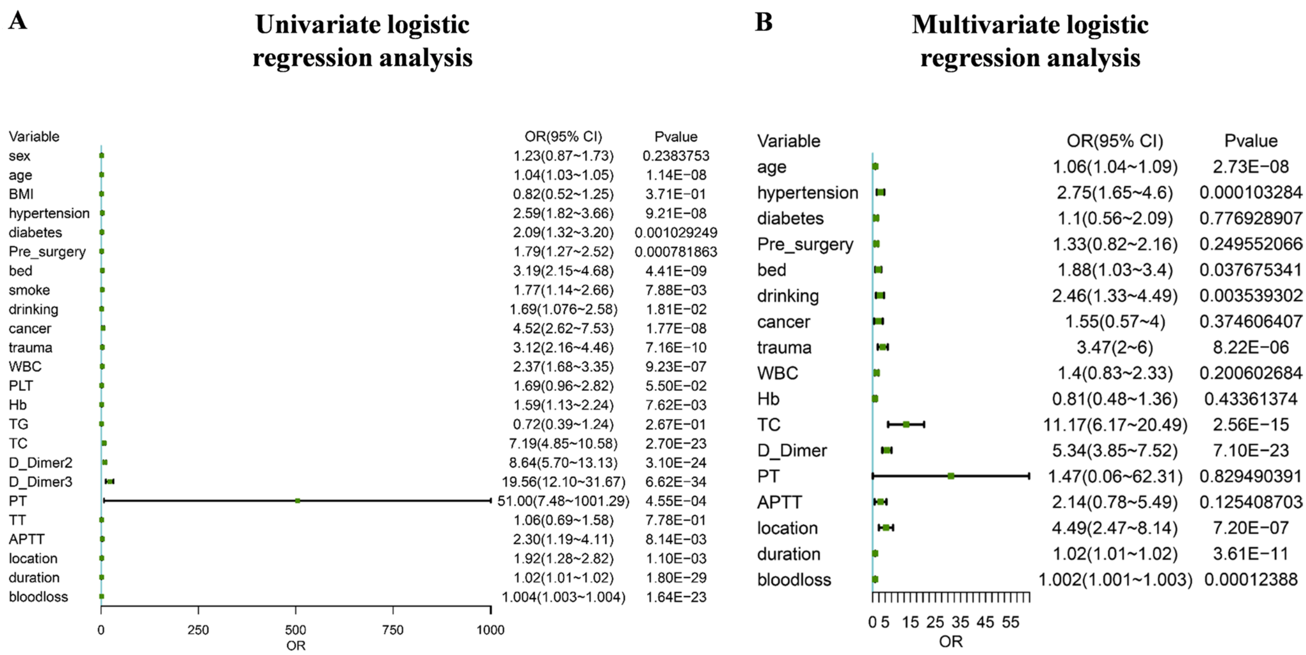

Fig. 1 The forest plot shows the results of univariate and multivariate analyses of VTE after spinal surgery. Notes: **A** In the univariate logistic analysis, 18 risk factors were presented. **B** In the multivariate logistic regression analysis, 10 independent risk factors for VTE were further screened out. *BMI* body mass index, *Pre_surgery* previous surgery, *WBC* white blood cell count, *PLT* platelet, *Hb* hemoglobin, *TG* triglyceride, *TC* total cholesterol, *PT* prothrombin time, *TT* thrombin time, *APTT* activated partial thromboplastin time

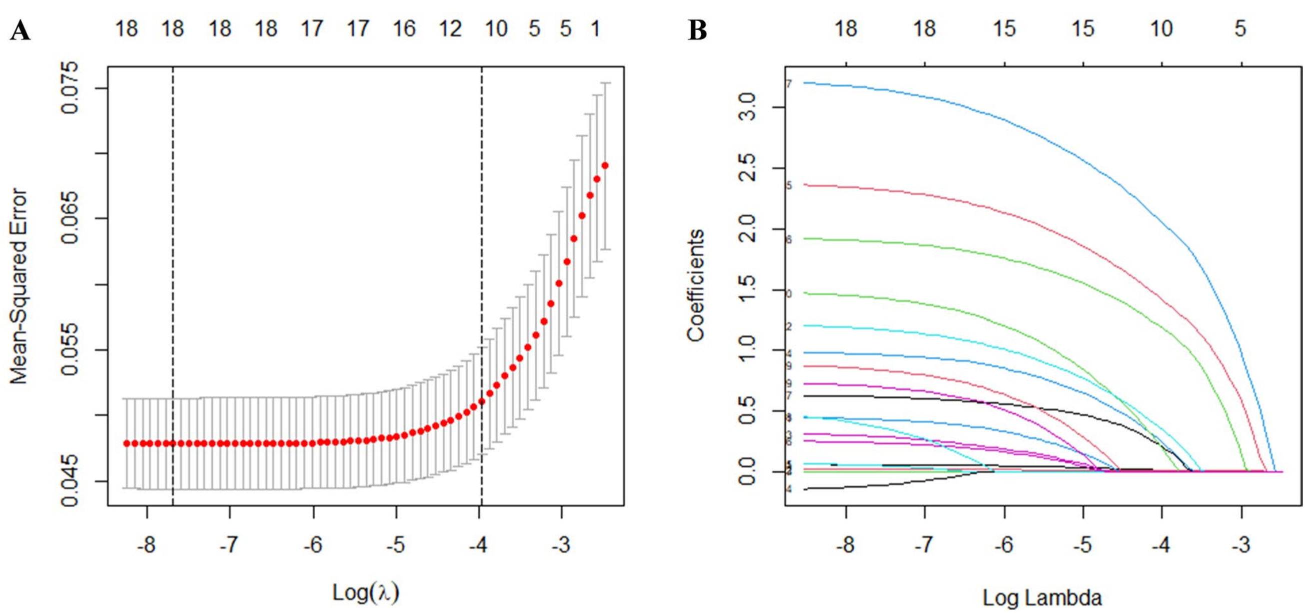

Fig. 2 The least absolute shrinkage and selection operator (LASSO) method for selecting postoperative deep vein thrombosis progression risk factors. Notes: **A** LASSO model was cross-validated using the minimum criterion, with dashed plumb lines drawn at the optimal values (9 factors). **B** The 18 feature LASSO coefficient profiles for logarithmic (lambda) sequences are constructed

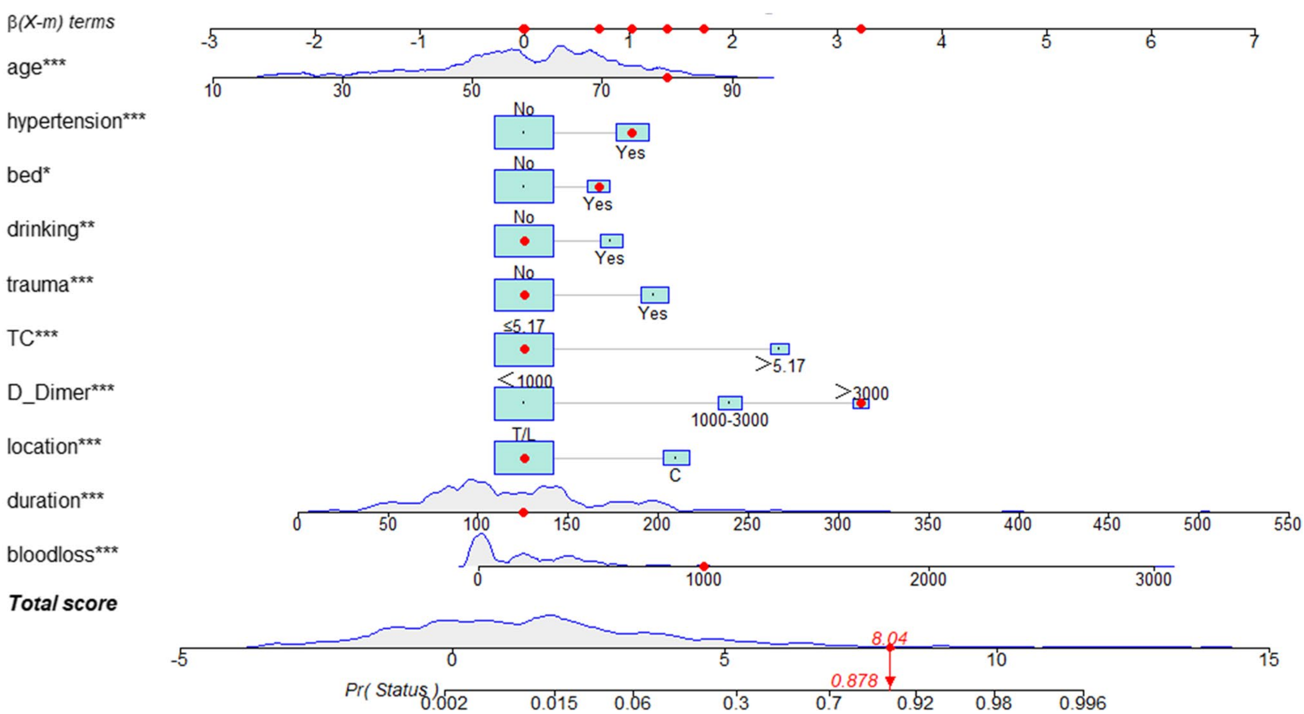

Fig. 3 A dynamic interactive nomogram was established to predict postoperative VTE in spinal surgery. The corresponding score for each factor is based on the condition of the patient, which can be determined by making a vertical line upwards (e.g., a patient with hypertension will receive between 70 and 75 scores). Add all the scores to get the total score, then find the corresponding point on the total points axis and make a vertical line down to predict the risk of VTE after spinal surgery. **P* < 0.05; ****P* < 0.001

Discussion

VTE is one of the most common complications in patients after spinal surgery. It presents with an insidious onset and can lead to severe complications such as stroke, pulmonary embolism, and even death, imposing a significant burden on patients and their families [16, 17]. Therefore, accurately assessing and predicting the risk of VTE in the early stages after spinal surgery is of crucial importance for prognosis. Thrombus formation is a complex process influenced by various factors, previous single-factor prediction models have failed to accurately predict the risk of thrombus formation and there is a scarcity of comprehensive multicenter studies and reliable clinical prediction models specifically focused on VTE after spinal surgery [18–24]. In this study, we analyzed data from 2754 cases of spinal surgery to identify ten independent risk factors for VTE occurrence and developed an interactive nomogram predictive model for postoperative VTE in spinal surgery. The model exhibited excellent discrimination and calibration capabilities, particularly evidenced by a high C-index in the interval validation, indicating its wide applicability and accuracy in predicting VTE occurrence risk in large sample sizes of spinal surgery patients. This predictive model can aid clinical practitioners in assessing and predicting the risk of VTE after spinal surgery, enabling timely adjustment of clinical decisions and effectively preventing the occurrence of VTE-related complications.

The findings of this study are consistent with previous single-factor studies, revealing several independent risk factors associated with VTE after spinal surgery. The identified risk factors include age, hypertension, bed, drinking, trauma, TC, D_dimer, location, duration, and bloodloss. The incidence of VTE is positively correlated with age. Gillum et al. demonstrated that for individuals aged 45–89, the incidence of VTE increases by 5‰ to 6‰ for every one-year increase in age [25]. Furthermore, a retrospective study by Masuda et al. involving 49,867 postoperative after spinal surgery found a significantly higher incidence of thrombosis in patients over 70 years of age compared to those under 50 years old [26]. This may be attributed to decreased vascular wall elasticity and impaired venous valve function in elderly patients, resulting in sluggish blood flow. Additionally, underlying conditions such as hypertension and diabetes can contribute to a prothrombotic state, increasing the risk of VTE occurrence [27, 28]. In our study, the average age of post-spinal surgery VTE patients was 64.76 ± 10.77 years, confirming advanced age as an independent risk factor for postoperative VTE. The International Consensus Meeting on Venous Thromboembolism (ICM-VTE) also emphasizes the importance of preoperative lower limb Doppler

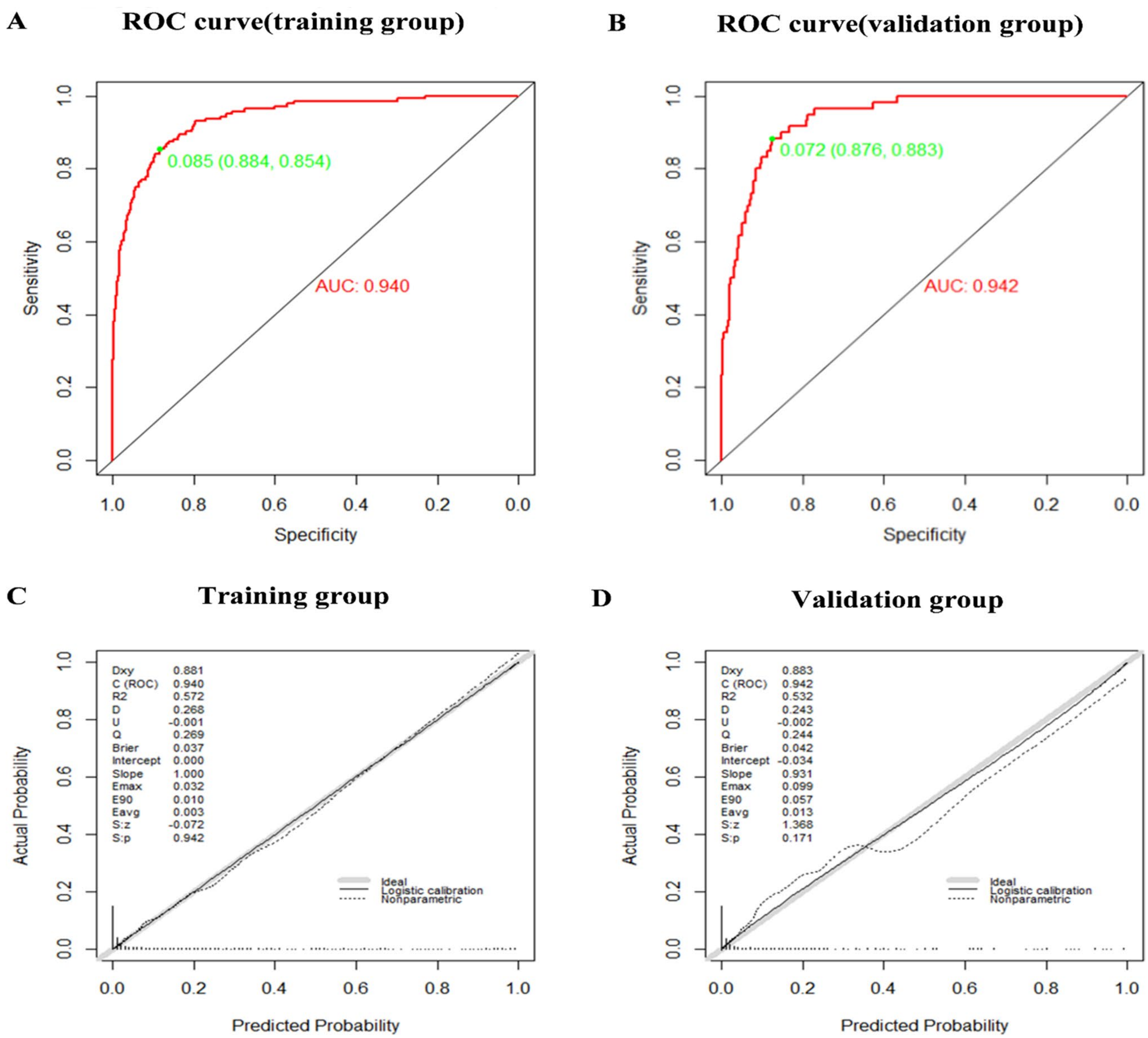

Fig. 4 The AUC of training group (AUC = 0.940) (**A**) and validation group (AUC = 0.942) **B** showed that the model had a high discrimination ability. **C**, **D** The calibration curves for assessing the consistency between the predicted and the actual risk of postoperative VTE. Favorable consistencies between the predicted and the actual risk evaluation are presented

ultrasonography to screen for deep venous thrombosis in elderly patients [29].

Hypertension is recognized as a major risk factor for the development of venous thromboembolism (VTE), which can be attributed to the endothelial damage caused by hypertension, leading to a prothrombotic state characterized by increased blood coagulability. Additionally, hypertension-induced cardiac overload can impair left ventricular function and result in reduced venous blood flow velocity or stasis, further augmenting the risk of thrombus formation. Li et al. conducted an analysis of the time of deep vein thrombosis formation in 1620 elderly patients undergoing lumbar spine surgery, revealing that hypertension during the first week after surgery can serve as one of the risk factors for VTE occurrence [30]. Consistent with previous literature reports [2, 18, 31], our study findings that patients with hypertension have a 2.75-fold increased risk of postoperative VTE compared to non-hypertensive patients (95% CI: 1.86–4.34). This highlights the clinical significance of hypertension as a notable risk factor for VTE after spinal surgery.

This study confirms that a prolonged bed exceeding 3 days significantly increases the risk of VTE after spinal

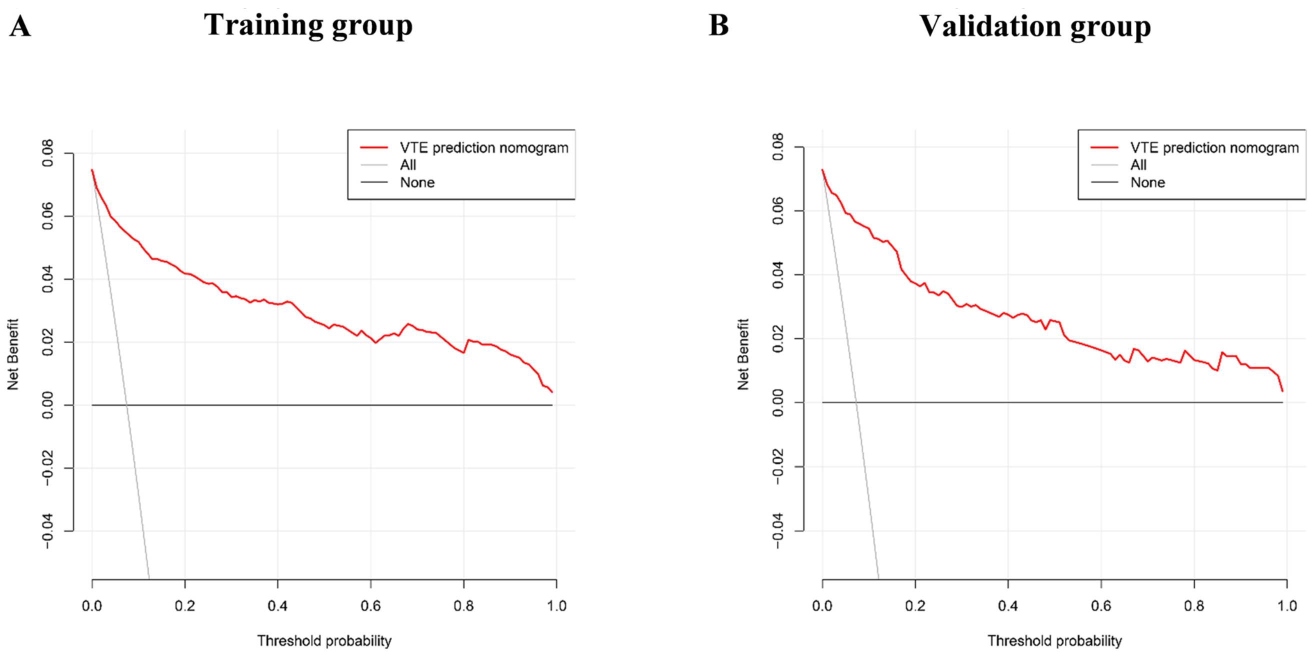

Fig. 5 DCA for the preoperative VTE progression nomogram. Notes: The Y-axis indicates the net benefit. The solid red line indicates the risk of preoperative DVT progression nomogram. The thin solid line indicates the assumption that progression of preoperative DVT is assumed to have occurred in all patients. The thick solid line indicates the hypothesis that no patients had progression of preoperative DVT. The decision curve demonstrated that using this preoperative DVT progression nomogram in the current study to predict preoperative DVT progression risk adds more benefit than either the intervention-all-patients scheme or the intervention-none scheme

surgery. Bed duration serves as an independent risk factor for postoperative VTE, aligning with previous literature reports [12, 18]. However, it is important to note that spinal surgery patients often require extended periods of bed rest, which can contribute to sluggish venous blood flow in the lower limbs and alterations in coagulation status, thereby increasing the risk of lower limb DVT occurrence.

The association between drinking and the risk of VTE remains controversial. Studies conducted by Zöller et al. have shown a higher incidence of VTE in individuals with excessive drinking among patients with autoimmune diseases [32]. Additionally, Freedman et al. suggested that excessive alcohol intake can decrease fibrinolytic activity, promote fibrinogen formation, activate platelets, increase blood viscosity, and elevate the risk of thrombus formation, consistent with the findings of this study [33]. However, some researchers argue that excessive drinking is not associated with an increased risk of VTE [34].

Previous studies have consistently demonstrated an elevated risk of VTE in patients with spinal trauma [35, 36]. In a retrospective study involving 195 patients, Cloney et al. reported a VTE incidence rate of 9.2% among individuals with fractures, which was significantly higher compared to the rate of 2.3% observed in non-fracture patients [37]. Furthermore, a multicenter study involving 6869 patients confirmed spinal fractures as an independent predictor of PE [36]. Additionally, Chuang et al. found that patients with spinal fractures complicated by spinal cord injury had a 2.46-fold increased incidence of DVT and a 1.57-fold increased incidence of pulmonary embolism compared to those with isolated spinal fractures, indicating a higher susceptibility to VTE [38]. Our study corroborates these findings by revealing a 3.47-fold higher risk of postoperative VTE in patients with spinal trauma compared to those without spinal trauma. Therefore, healthcare professionals should be cautious about the risk of fatal pulmonary embolism resulting from DVT in patients admitted with spinal trauma, particularly those with concomitant spinal cord injuries.

Hyperlipidemia significantly increases blood viscosity, leading to the development of atherosclerosis and endothelial plaque formation [39]. Lauren et al. observed a significant elevation in the recurrence rate of VTE among patients with hyperlipidemia [40]. In our study, patients with elevated serum TC exhibited an 11.17-fold higher incidence of VTE compared to individuals with normal cholesterol levels, highlighting elevated total cholesterol as an independent risk factor for VTE. Moreover, Alanna M demonstrated that high-density lipoprotein cholesterol (HDL-C) is not a risk factor for VTE [41]. Therefore, patients with pre-existing hyperlipidemia are more susceptible to DVT, necessitating dietary guidance and early anticoagulation therapy to prevent postoperative VTE.

Elevated D-dimer is widely recognized as a risk factor for VTE occurrence [42]. D-dimer serves as a sensitive biomarker for fibrinolysis and coagulation, and it can also indicate the presence of clinically elusive microthrombus formation [43]. Inoue et al. assessed the changes in D-dimer levels following low-risk spinal surgery and found that elevated D-dimer levels on the third and seventh postoperative days were predictive factors for early VTE diagnosis after spinal surgery [44]. Our study revealed that elevated D-dimer levels increased the risk of VTE in patients undergoing spinal surgery by approximately 6.21 times. The rise in D-dimer levels is attributed to the hypercoagulable state during surgery or trauma, thereby elevating the risk of VTE occurrence [45]. Therefore, perioperative physicians should dynamically monitor D-dimer levels to effectively predict the development of VTE following spinal surgery.

According to Kepler, patients undergoing posterior cervical fusion surgery have the highest incidence of VTE at 1.34% [46]. Similarly, Oglesby and his colleagues found a DVT incidence of 1.3% in patients undergoing posterior cervical fusion (PCF), while anterior cervical decompression and fusion (ACF) had an incidence below 0.5% [47]. This trend suggests that the PCF group is influenced by factors such as age, surgical exposure, and fusion stages, which consequently increase the risk of VTE occurrence. Sebastian et al. evaluated the VTE incidence in 43,777 patients who underwent thoracolumbar spine surgery using the American College of Surgeons National Surgical Quality Improvement Program database from 2005 to 2012, they found DVT and PE incidence rates of 0.7% and 0.5%, respectively, in patients undergoing lumbar spine surgery [18]. In another retrospective study by Ballard, involving 617 patients who underwent anterior approach thoracic and/or thoracolumbar spine surgeries, the DVT incidence rate was 2% [48]. Our study also revealed that the risk of VTE after cervical spine surgery was 4.49 times higher than after thoracolumbar spine surgery. Therefore, implementing earlier and more proactive VTE prevention strategies is beneficial, particularly in cervical spine surgeries, especially in PCF.

Prolonged surgery duration and increased intraoperative bleeding are associated with a higher risk of VTE after spine surgery. The body's production and release of excessive inflammatory factors, as well as the aggregation of these factors, contribute to the increased risk of VTE [49]. Wang et al. proposed that intraoperative blood loss exceeding 2000 mL significantly increases the risk of DVT [50]. Our study also confirms that both surgery duration and intraoperative blood loss are independent risk factors for VTE occurrence after spine surgery.

Therefore, the establishment of predictive models would assist physicians in assessing the VTE risk in patients and implementing timely intervention measures when there is a high likelihood of obtaining favorable net benefits [51]. This approach would help reduce complications and hospitalization costs. In reality, predicting VTE occurrence in individual patients is challenging, and timely detection and multifaceted interventions may be the most effective approach for VTE prevention.

Several limitations of this study should be addressed in future researches. Firstly, this research were single-center and retrospective study, there may have been potential bias, such as patient selection. Secondly, there is no subgroup analysis of some high-risk factors, such as hypertension classification, postoperative bed rest time, alcohol consumption, use of implants, and plasma cholesterol subtyping, which may hinder the precise diagnosis and treatment of high-risk patients. Finally, patients who underwent intervertebral disc arthroscopy and vertebral body cement augmentation were not included in this study because such patients have a short hospital stay and are discharged within 1–2 days after surgery without postoperative vascular ultrasound data, which may result in the loss of valuable information and affect the accuracy of the study results.

Conclusions

In conclusion, the independent risk factors for postoperative VTE in spinal surgery include age, hypertension, bed rest for more than 3 days, drinking, trauma, triglyceride, D-dimer, surgical location, operation duration, and blood loss, especially in patients with multiple risk factors, early intervention should be taken to prevent the occurrence of VTE. The VTE prediction model established by our team is simple and feasible, on the one hand, it can be used by Primary Healthcare and Medical Institution to educate and provide information to patients with spinal disorders who are undergoing conservative treatment, change daily lifestyle such as a low-cholesterol diet, limited alcohol consumption, effective blood pressure control, appropriate physical activity and so on. The patients take proactive measures for preventive care, thereby reducing the risk of potential complications. On the other hand, it can also encourage the spinal surgeons to improve their surgical skills, choose the most suitable surgical techniques, minimize surgical duration, and reduce blood loss et al., in order to achieve the purpose of passive prevention for patients undergoing spine surgery. By combining proactive and passive prevention strategies, intervention for high-risk factors of VTE throughout entire spinal disorder management can more effectively prevent the occurrence of VTE after spinal surgery.

Author contributions WQK wrote the first draft of the manuscript. WQK, CS, YKD, JLL, JLS, HQH and YQ collected and analyzed the data. YMX supervised the work.

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Data availability Datasets of the current study are available from the corresponding authors upon reasonable request.

Declarations

Conflict of interest The authors, their immediate family, and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity for the preparation of this article.

Ethics approval The studies involving human participants were reviewed and approved by medical ethics review committee of the Affiliated Hospital of Qingdao University. The patients/participants provided their written informed consent to participate in this study.

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