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ORIGINAL ARTICLE

A Nomogram Prediction Model Integrating TEG and Clinical Features for Postoperative Lower Extremity DVT in TF Patients

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SUMMARY

Background: **The goal was to identify risk factors for postoperative lower extremity deep vein thrombosis (DVT) in traumatic lower limb fracture patients and establish a nomogram prediction model for clinical risk assessment and management.**

Methods: **A total of 136 lower extremity traumatic fracture (LETF) patients admitted to the emergency surgery department were enrolled. Patients were divided into DVT and non-DVT groups based on postoperative color Doppler ultrasonography. Univariate and multivariable logistic regression analyses were performed to determine independent risk factors for DVT. A nomogram prediction model was constructed and validated using receiver operating characteristic curve analysis, calibration curve, and decision curve analysis (DCA).**

Results: **Among 136 patients, 52 developed DVT, while 84 did not. No significant differences were observed in age, gender, BMI, hypertension, coronary artery disease, time from injury to surgery, operative duration, or American Society of Anesthesiologists score (all $p > 0.05$). However, diabetes prevalence, intraoperative transfusion rate, hip versus tibiofibular fracture distribution, injury severity score (ISS) score ≥ 25, hemoglobin, hematocrit, fibrinogen (FIB), and D-Dimer (D-D) levels differed significantly (all $p < 0.05$). Thromboelastography (TEG) revealed significantly higher maximum amplitude (MA) and α-angle, but lower clot formation time (K) value in the DVT group (all $p < 0.001$). Multivariable analysis identified hip fracture, ISS ≥ 25, elevated FIB, elevated D-D, increased MA, and decreased K as independent risk factors (all $p < 0.05$). The nomogram demonstrated excellent predictive performance (area under the curve = 0.89, 95% confidence interval: 0.77 - 1.00), good calibration (Hosmer-Lemeshow test $p > 0.05$), and clinical utility on DCA.**

Conclusions: **The TEG-based nomogram incorporating clinical features effectively predicts postoperative DVT risk in traumatic fracture patients, facilitating early identification of high-risk individuals and personalized prophylaxis to mitigate DVT incidence and improve outcomes.**

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KEYWORDS

Thromboelastography, lower extremity traumatic fracture, deep vein thrombosis, nomogram, predictive model

INTRODUCTION

Deep vein thrombosis (DVT) refers to the condition where blood abnormally coagulates within the deep veins, obstructing the lumen and causing venous return impairment [1]. In lower extremity traumatic fracture (LETF) patients, the postoperative incidence of DVT is

relatively high. If not detected and intervened promptly, the thrombus may dislodge and enter the pulmonary circulation, leading to life-threatening pulmonary embolism [2]. The post-fracture hypercoagulability, along with factors such as limb immobilization and surgery, may increase the DVT risk [3]. Clinically, early symptoms of lower extremity DVT are nonspecific and often subtle. Only 10 - 17% of DVT patients exhibit obvious clinical symptoms (including limb swelling, localized deep tenderness, or pain upon dorsiflexion), which can easily lead to misdiagnosis or missed diagnosis [4]. Although the exact mechanisms of postoperative DVT in LETF remain incompletely understood, the condition is widely recognized as a multifactorial process. Virchow's triad, first proposed in 1856, remains the fundamental framework for explaining DVT pathogenesis [5]. Recent advances in medical technology and clinical research have identified established risk factors for DVT in LETF [6-8]. One study indicates that postoperative DVT is closely associated with patient age, diabetes history, and postoperative hemoglobin decline [9]. Another study, through ultrasound analysis, identified prolonged surgical duration, lack of postoperative active or passive movement, and fracture location as additional risk factors [10]. Changes in coagulation status also play a critical role in DVT development. Studies suggest that preoperative hypercoagulability detected via thromboelastography (TEG) significantly correlates with postoperative DVT formation, highlighting the importance of preoperative coagulation monitoring in predicting thrombotic events [11]. Elevated plasma fibrinogen (FIB) and D-dimer (D-D) levels are also recognized as independent risk factors for postoperative DVT, serving as early predictive markers [12]. Given the severe impact of DVT on patient prognosis, early identification of high-risk individuals and targeted preventive measures are crucial. However, current clinical practice lacks an accurate, convenient, and clinically practical predictive tool. Traditional DVT risk assessment methods rely heavily on physician experience and routine tests such as coagulation studies and D-D [13]. These indicators often reflect only isolated aspects of the coagulation system, lacking comprehensiveness with limitations in sensitivity and specificity.

Like other forms of viscoelastic testing, thromboelastography (TEG) represents an innovative coagulation monitoring technology capable of dynamically and comprehensively assessing the entire hemostatic process from clot initiation to fibrinolysis [14,15]. It provides detailed insights into coagulation factor activity, platelet function, and fibrin formation and dissolution, offering more comprehensive coagulation data [16]. In recent years, TEG has been widely applied across various medical fields, demonstrating unique advantages in predicting thrombotic risk [17,18]. In LETF, studies suggest an association between TEG parameters and postoperative DVT [19]. However, relying solely on TEG parameters may be insufficient, as DVT development involves multiple contributing factors, including clinical features such as age, gender, fracture type, and injury severity. The nomogram, as an intuitive graphical prediction tool, simplifies complex regression models into an easily interpretable format for clinical use [20]. By quantifying independent risk factors based on their predictive weight and assigning corresponding scores, it calculates a total score to estimate the outcome probability, enabling individualized risk prediction.

Therefore, this study aims to integrate TEG parameters with clinical features of traumatic lower extremity fracture patients to construct a comprehensive nomogram prediction model for assessing postoperative DVT risk. This model is expected to provide clinicians with a more scientific and accurate predictive tool, facilitating early identification of high-risk patients and timely preventive interventions. Ultimately, it may help reduce postoperative DVT incidence and improve patient prognosis and quality of life.

MATERIALS AND METHODS

Study subjects

A total of 136 patients with LETF admitted to the emergency surgery department of The Affiliated Hospital of Xuzhou Medical University from January 2023 to December 2024 were enrolled. Inclusion criteria: 1) Patients aged > 18 years, with preoperative color Doppler ultrasound excluding lower extremity DVT and presenting with fresh fractures (≤ 3 weeks); 2) Patients meeting surgical indications and undergoing surgical treatment; 3) Patients with acceptable preoperative risk assessment and deemed suitable for surgery; 4) Patients without a history of venous thromboembolism; 5) Patients with complete clinical data. Exclusion criteria: 1) Patients with hepatic or renal insufficiency, immune system disorders, or malignant tumors; 2) Patients with old fractures or multiple fractures; 3) Patients receiving recent anticoagulant therapy; 4) Patients undergoing other major surgeries within 30 days before enrollment; 5) Pregnant or menstruating women; 6) Patients with incomplete clinical data. All participants and their families provided informed consent, and the study was approved by the Medical Ethics Committee of The Affiliated Hospital of Xuzhou Medical University.

Methods

Diagnostic criteria

During hospitalization, lower extremity veins were examined using a Doppler ultrasound system (Siemens Healthineers, China; model: ACUSON Sequoia). According to the Guidelines for the diagnosis and treatment of deep venous thrombosis (3rd edition), patients presenting with lower limb swelling, pain, tenderness in the calf and/or medial thigh, hypercoagulability (D-D > 500 μg/L DDU, equivalent to 0.5 mg/L FEU), non-compressible veins on B-mode ultrasound, and heterogeneous intraluminal echoes underwent further evaluation with color Doppler ultrasound and CT venography.

DVT diagnosis was confirmed by observing vascular filling defects or incomplete luminal opacification. Based on postoperative DVT occurrence, patients were classified into the DVT group (n = 52) and the non-DVT group (n = 84).

Clinical data

All clinical data were collected by a trained senior clinician. The collected variables included: gender, age, body mass index (BMI), comorbidities, duration of surgery, intraoperative blood transfusion, anesthesia method, American Society of Anesthesiologists (ASA) classification, fracture location (hip fracture, femoral shaft fracture, peri-knee fracture, tibiofibular fracture, and ankle fracture), and injury severity score (ISS) (range: 0 - 75, with higher scores indicating more severe trauma).

Laboratory tests

On the first postoperative morning, 2 mL of peripheral venous blood was collected from TF patients and placed in sodium citrate anticoagulant tubes. TEG analysis was performed using a HAS-300 analyzer (Suzhou Healthath Biotechnology Co., Ltd.). Whole blood samples were mixed with coagulation activators in a test cup, and the instrument automatically recorded parameters including maximum amplitude (MA), α-angle, clot formation time (K), and reaction time (R). An additional 2 mL of peripheral blood was collected in ethylenediaminetetraacetic acid tubes for complete blood count analysis (hemoglobin, hematocrit, platelet count) using an automated hematology analyzer. Plasma was separated by centrifugation at 3,200 rpm (8 cm radius) for 10 minutes, followed by FIB and D-D measurements using a fully automated biochemical analyzer (Mindray CX-9000).

Statistical analysis

Data analysis was performed using Statistical Package for the Social Sciences 28.0. Normally distributed continuous variables were expressed as mean ± standard deviation and compared using Student's t-test. Non-normally distributed continuous variables were presented as median (interquartile range) (M [P25, P75]) and analyzed using the Mann-Whitney U test. Categorical variables were reported as frequencies (percentages) and compared using the chi-squared test.

Stepwise backward logistic regression was used to identify risk factors for DVT in LETF patients, with multicollinearity diagnostics performed. A DVT risk prediction model was constructed using R 4.2.3 and the rms package. The discriminative ability of the nomogram was assessed using receiver operating characteristic (ROC) curve analysis, while calibration curves and the Hosmer-Lemeshow goodness-of-fit test evaluated its accuracy. Decision curve analysis was used to assess clinical utility. A two-sided $p < 0.05$ was considered statistically significant.

RESULTS

Comparison of clinical features between DVT and non-DVT groups

The study compared clinical features between DVT and non-DVT groups in LETF patients. No statistically significant differences were observed between the two groups regarding age, gender, BMI, hypertension, coronary heart disease, time from fracture to surgery, operative duration, or ASA classification ($p > 0.05$). However, the prevalence of diabetes was significantly higher in the DVT group ($p = 0.032$). Regarding intraoperative blood transfusion, the DVT group had a significantly higher transfusion rate ($p = 0.023$). Fracture location analysis revealed significant differences in hip fractures and tibiofibular fractures ($p < 0.001$), with the DVT group showing a lower proportion of hip fractures and a significantly lower proportion of tibiofibular fractures. The DVT group also had a significantly higher proportion of patients with ISS scores ≥ 25 ($p < 0.001$). Laboratory results demonstrated that hemoglobin and hematocrit levels were significantly lower in the DVT group ($p < 0.05$), while FIB and D-D levels were significantly higher ($p < 0.001$). No significant difference was observed in platelet counts ($p > 0.05$). These findings suggest that diabetes, intraoperative blood transfusion, anesthesia method, fracture location, ISS score, and certain laboratory parameters may be associated with postoperative DVT in LETF patients. These factors provide important evidence for constructing a nomogram prediction model combining TEG parameters with clinical features (Table 1).

Comparison of TEG parameters between DVT and non-DVT groups

This study compared TEG parameters between DVT and non-DVT groups in LETF patients. The results demonstrated that the MA was significantly higher in the DVT group, with median values of 72.22 mm (66.78, 76.81) versus 65.81 mm (63.12, 69.87) in the non-DVT group ($p < 0.001$). The α-angle was also significantly greater in the DVT group (mean 76.24° ± 3.57°) compared to the non-DVT group (72.98° ± 3.68°) ($p < 0.001$). Regarding K, the DVT group exhibited significantly lower values (median 1.11 minutes [0.93, 1.32]) than the non-DVT group (1.44 minutes [1.27, 1.68]) ($p < 0.001$). No significant difference was observed in R between groups (4.95 ± 1.12 minutes vs. 5.04 ± 1.05 minutes, $p = 0.637$). These findings suggest that MA, α-angle, and K values may be associated with postoperative DVT development in LETF patients, providing supportive data for constructing a TEG-incorporated nomogram prediction model (Figure 1, Table 2).

Multivariate analysis of risk factors for postoperative DVT in traumatic lower extremity fracture patients

Using postoperative DVT occurrence (present = 1, absent = 0) as the dependent variable, with adjustments

Table 1. Comparison of clinical data between DVT and non-DVT Groups.

Variable	Non-DVT group (n = 84)	DVT group (n = 52)	p-value
Age	50 (44, 54)	51 (45, 59)	0.248
Gender			
Male	52 (61.90%)	28 (53.85%)	0.375
Female	32 (38.10%)	24 (46.15%)	
BMI	23.89 ± 2.48	23.48 ± 2.54	0.355
Comorbidities			
Hypertension	29 (34.52%)	19 (36.54%)	0.855
Diabetes	13 (15.48%)	17 (32.69%)	0.032
Coronary heart disease	20 (23.81%)	17 (34.62%)	0.238
Time from fracture to	5.45 ± 1.04	5.63 ± 1.13	0.344
Operation time (minute)	124.74 ± 65.36	118.45 ± 61.94	0.579
Intraoperative blood transfusion			
Yes	52 (61.90%)	42 (80.77%)	0.023
No	32 (38.10%)	10 (19.23%)	
ASA score (general anesthesia)			
1	14 (16.67%)	5 (9.62%)	0.296
2	46 (54.76%)	26 (50.00%)	
3	24 (28.57%)	21 (40.38%)	
Fracture site			
Hip fracture	8 (9.52%)	22 (42.31%)	< 0.001
Femoral shaft fracture	27 (32.14%)	11 (21.15%)	0.176
Peri-Knee fracture	14 (16.67%)	10 (19.23%)	0.818
Tibia-Fibula fracture	25 (38.10%)	7 (7.69%)	0.037
Foot-Ankle fracture	10 (11.90%)	2 (3.85%)	0.130
ISS score			
< 25	58 (71.43%)	19 (36.54%)	< 0.001
≥ 25	24 (28.57%)	33 (63.46%)	
Laboratory tests			
Hemoglobin (g/L)	130.45 ± 18.17	120.67 ± 15.44	0.002
Hematocrit (%)	41.10 ± 4.95	39.24 ± 4.81	0.033
Platelets (× 10^9/L)	212.03 ± 70.09	224.82 ± 67.74	0.297
Fibrinogen (g/L)	3.38 ± 1.11	4.29 ± 0.95	< 0.001
D-Dimer (mg/L FEU)	1.88 (1.76, 2.01)	2.13 (1.99, 2.27)	< 0.001

Table 2. Comparison of TEG parameters between DVT and non-DVT Groups.

Variable	Non-DVT group (n = 84)	DVT group (n = 52)	p-value
MA (mm)	65.81 (63.12, 69.87)	72.22 (66.78, 76.81)	< 0.001
α-angle (°)	72.98 ± 3.68	76.24 ± 3.57	< 0.001
K (minute)	1.44 (1.27, 1.68)	1.11 (0.93, 1.32)	< 0.001
R (minute)	5.04 ± 1.05	4.95 ± 1.12	0.637

Table 3. Multivariate logistic regression analysis of factors influencing DVT in lower extremity traumatic fracture.

Variable	β	S.E	Z	P	OR (95% CI)
Intercept	-27.90	8.56	-3.26	0.001	0.00 (0.00 - 0.00)
Hip Fracture	2.41	1.0	2.41	0.016	11.5 (1.57 - 78.88)
ISS	2.63	0.90	2.92	0.003	13.86 (2.38 - 80.71)
Fibrinogen	1.67	0.52	3.20	0.001	5.31 (1.91 - 14.78)
D-Dimer	3.87	1.62	2.39	0.017	47.72 (2.00 - 1,138.82)
MA	0.26	0.09	2.87	0.004	1.30 (1.09 - 1.55)
K	-4.94	1.57	-3.16	0.002	0.01 (0.00 - 0.15)

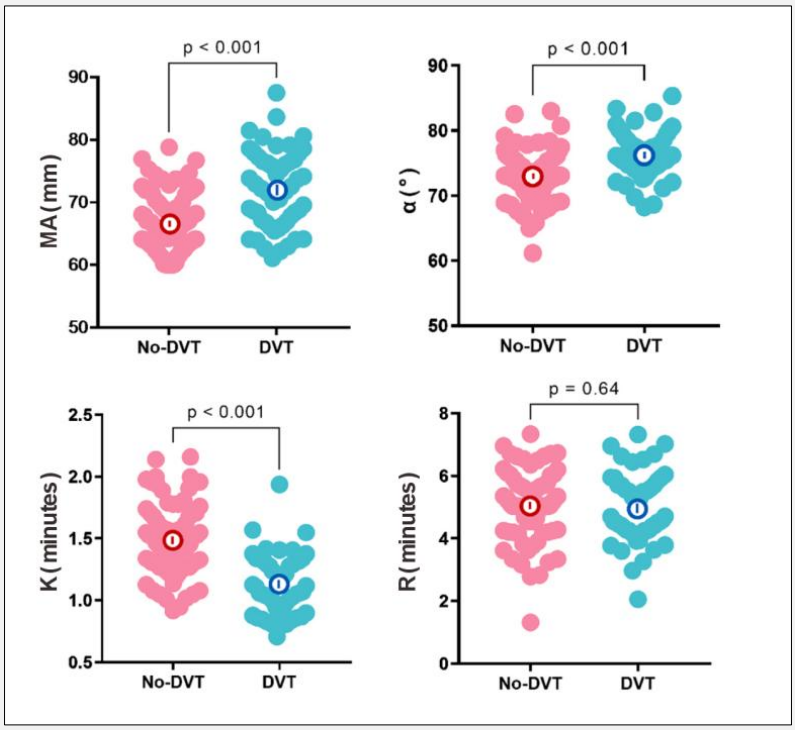

Figure 1. Comparison of TEG parameters between DVT and non-DVT groups.

for gender and age, significant factors from univariate analysis were included as independent variables in a backward stepwise multivariate logistic regression. The results identified hip fracture, ISS ≥ 25, elevated FIB, elevated D-D, increased MA, and decreased K as independent risk factors for postoperative DVT ($p < 0.05$, Table 3). Collinearity diagnostics were performed for these significant factors (hip fracture, ISS, FIB, D-D, MA, and K). Tolerance values ranged from 0.857 to 0.945, and variance inflation factors (VIF) were between 1.058 and 1.167, confirming no multicollinearity (all tolerance > 0.1, VIF < 10).

Development and validation of a nomogram prediction model for postoperative DVT in traumatic lower extremity fracture patients

The nomogram incorporated six predictors: hip fracture, ISS ≥ 25, FIB, D-D, MA, and K values (Figure 2). Model discrimination showed excellent predictive performance (area under the curve [AUC] = 0.89, 95%

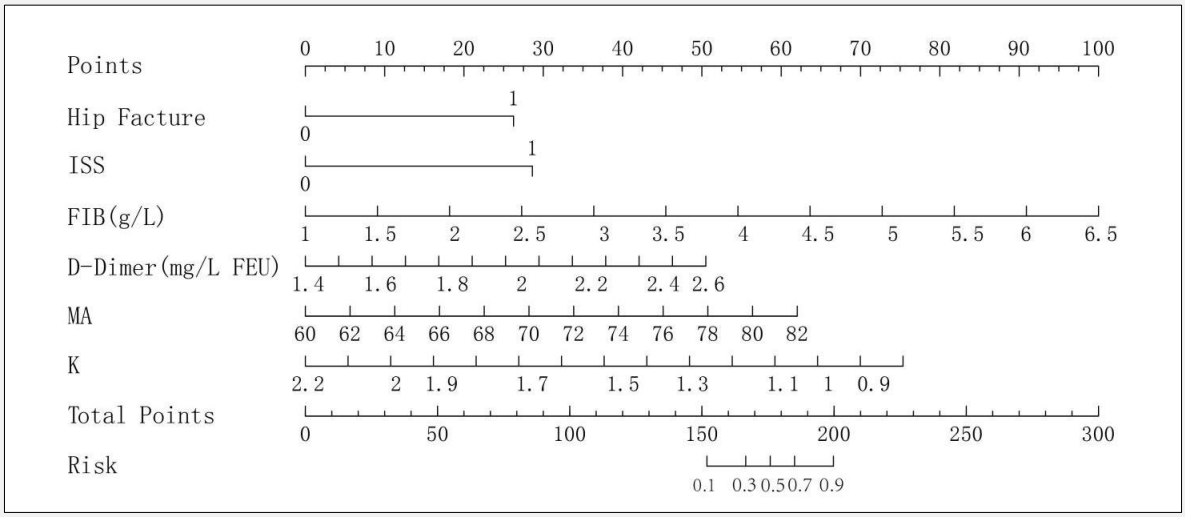

Figure 2. Nomogram model for postoperative DVT risk in LETF patients.

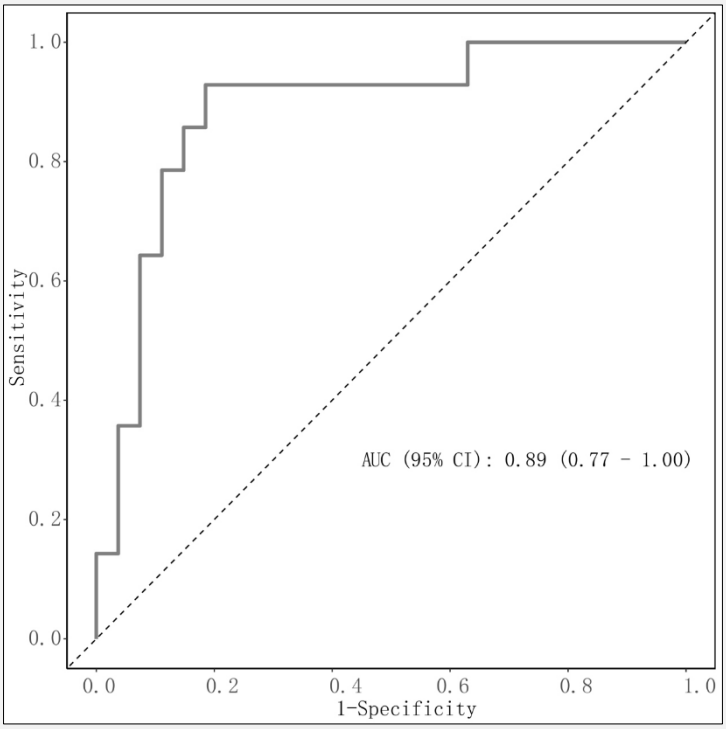

Figure 3. ROC curve of the nomogram model.

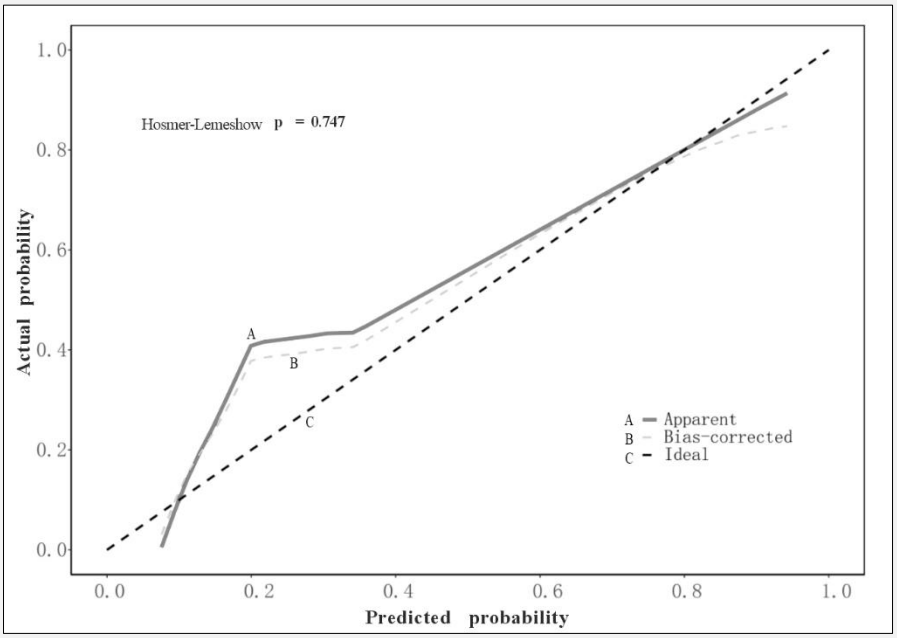

Figure 4. Calibration curve of the nomogram.

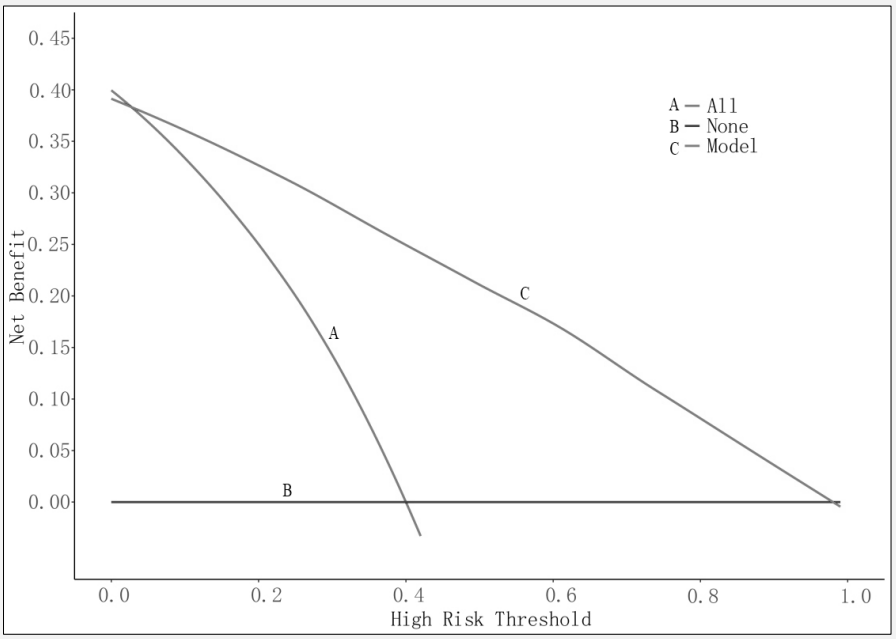

Figure 5. Decision curve analysis of the nomogram.

confidence interval [CI]: 0.77 - 1.00; Figure 3). Calibration analysis demonstrated good agreement between predicted and observed probabilities (calibration curve, Figure 4; Hosmer-Lemeshow test: $\chi^2 = 5.102$, p = 0.747). Decision curve analysis confirmed superior net benefit across clinically relevant threshold probabilities compared to alternative strategies (Figure 5).

DISCUSSION

This study aimed to develop a nomogram predicting postoperative lower-extremity DVT in traumatic fracture patients by integrating TEG parameters with clinical features and to comprehensively evaluate its predictive performance. The results demonstrated that the developed model exhibits excellent discriminative ability, accuracy, and clinical applicability, providing a novel and effective tool for clinical prediction of postoperative DVT in these patients.

Risk factor analysis identified hip fracture, ISS ≥ 25, elevated FIB, elevated D-D, increased MA, and decreased K as independent risk factors for postoperative DVT. Hip fracture patients, due to the specific fracture location requiring prolonged immobilization, experience reduced venous blood flow velocity. The substantial surgical trauma also predisposes to vascular endothelial injury, activating the coagulation system and increasing DVT risk. Hip and femoral shaft fractures typically result from high-energy trauma, causing severe soft tissue damage and inflammatory mediator release, while the associated stress response promotes hypercoagulability and endothelial injury [21]. The ISS, a clinical measure of trauma severity [22], reflects the degree of systemic injury. Scores ≥ 25 indicate severe trauma with consequent increased stress and coagulation-fibrinolysis imbalance, increasing thrombotic tendency [23]. FIB and D-D, as crucial coagulation markers, show strong associations with DVT development [4,12]. Elevated FIB increases blood viscosity and promotes thrombus formation [24], while elevated D-D indicates activated coagulation and fibrinolysis, serving as an important diagnostic and prognostic marker for DVT [25, 26]. The significantly higher FIB and D-D levels in the DVT group further validate their roles in DVT pathogenesis.

TEG demonstrates superior sensitivity over conventional coagulation tests in predicting DVT formation, offering deeper insights into coagulation status [16,18]. Among TEG parameters, MA, α-angle, and K time significantly correlate with DVT occurrence [11,27,28]. Gong et al. [29] identified postoperative changes in R time, K time, α-angle, and MA as predictive of DVT in gastric cancer patients with portal hypertension. Using meta-analysis, Jiang et al. [30] demonstrated that TEG provides more accurate indicators of coagulation status in cancer patients than existing clinical tests and that combining TEG with the Wells score could predict DVT formation. In this study, DVT patients exhibited significantly higher MA and alpha angle, and lower K values than non-DVT patients, indicating a hypercoagulable state with accelerated coagulation kinetics and enhanced clot strength. Compared to traditional coagulation tests, TEG's advantages lie in its use of whole blood, rapid analysis time, and provision of comprehensive information on the dynamic clot formation and strength [31].

The developed nomogram demonstrated high predictive value, with ROC analysis showing an AUC of 0.89 (95% CI: 0.77 - 1.00), indicating excellent discrimination between patients developing versus not developing postoperative DVT. Calibration curves and Hosmer-Lemeshow testing ($\chi^2 = 5.102$, $p = 0.747$) confirmed strong agreement between predicted and observed outcomes. Decision curve analysis revealed clinically meaningful utility across probability thresholds of 10 - 60%, supporting its use for preoperative risk stratification and individualized prophylaxis planning.

This study innovatively integrates TEG parameters and clinical features for DVT prediction modeling. Previous research largely focused on single clinical factors or laboratory indicators, whereas combining TEG's comprehensive and dynamic assessment of coagulation status with clinical features enhances model accuracy and reliability. Furthermore, stringent inclusion/exclusion criteria selected a relatively homogeneous cohort of acute traumatic lower-extremity fracture patients, minimizing confounding factors and strengthening result credibility. However, limitations exist: 1) The relatively small sample size may impact model stability and generalizability. Future research should expand the sample size and conduct multicenter studies to further validate model reliability; 2) Being a retrospective study, selection and information bias may exist. Prospective studies are warranted to more accurately assess the model's predictive performance.

In summary, the nomogram prediction model for postoperative DVT in traumatic fracture patients, developed by integrating TEG and clinical features, demonstrated high predictive value, accuracy, and clinical applicability, offering a novel approach for DVT prediction. However, future expansion of the sample size and prospective validation studies are necessary to refine and optimize the model.

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Data available:
Data is available from the corresponding author on request.

Ethics statement:
The present study was approved by the Ethics Committee of The Affiliated Hospital of Xuzhou Medical University (No.202103XZ-5) and written informed consent was provided by all patients prior to the study start. All procedures were performed in accordance with the ethical standards of the Institutional Review Board and The Declaration of Helsinki, and its later amendments or comparable ethical standards.

Declaration of Interest:
The authors have no conflicts of interest to declare.

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