


Derivation and External Validation of a Risk Assessment Model of Venous Thromboembolism in Hospitalized Chinese Patients

Clinical and Applied
Thrombosis/Hemostasis
Volume 29: 1-10
© The Author(s) 2023
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/10760296221151164
journals.sagepub.com/home/cat


Xiaolan Chen¹ , Jiali Huang¹, Jinxuan Liu¹, Jiaqi Chang², Lei Pan¹, Yong Wang³ , Yuan Gao⁴, and Yuanhua Yang⁴ 

Abstract

Aim: To develop and validate a risk assessment model (RAM) of venous thromboembolism (VTE) in hospitalized Chinese patients.

Methods: We reviewed data from 300 patients with VTE and 300 non-VTE patients at Beijing Shijitan Hospital. The risk factors related to VTE were analyzed, and the VTE RAM (Shijitan (SJT) version) was developed according to the weight of each risk factor. A total of 407 patients with VTE and 533 non-VTE patients were enrolled for external validation. The sensitivity, specificity, Youden index, receiver operating curve (ROC), and area under the ROC curve (AUC) were used to evaluate the performance of VTE RAM (SJT version) compared with Caprini RAM and Padua RAM.

Results: The VTE RAM (SJT version) contained six risk factors (age >60 years, lower limb edema, chronic obstructive pulmonary disease (COPD), central venous catheterization (CVC), VTE history, and D dimer). In the external validation group, for medical patients, the AUC value of SJT RAM (0.82 ± 0.03) is significantly higher than Caprini RAM (0.76 ± 0.04 ; $P < 0.05$), SJT RAM has a higher sensitivity, specificity, and Youden index than Caprini RAM ($P < 0.05$), which means that the SJT RAM has a much better predictive value than Caprini RAM. While SJT RAM and Padua RAM have the similar predictive value for medical patients ($P > 0.05$). For surgical patients, the AUC value of SJT RAM (0.72 ± 0.04) is significantly higher than the value of Padua RAM (0.66 ± 0.04 ; $P < 0.05$), SJT RAM has a higher sensitivity, specificity, and Youden index than Padua RAM ($P < 0.05$), which shows that the VTE RAM has better predictive value than Padua RAM. While SJT RAM and Caprini RAM have the similar predictive value for surgical patients ($P > 0.05$).

Conclusion: The SJT RAM derived from general hospitalized Chinese patients will be time-saving for physicians and has a better predictive ability for patients at risk of VTE.

Keywords

venous thromboembolism, risk assessment model, Chinese inpatients, development, external validation

Date received: 14 October 2022; revised: 23 December 2022; accepted: 30 December 2022.

Introduction

Venous thromboembolism (VTE) includes deep vein thrombosis (DVT) and pulmonary embolism (PE) and is the most likely preventable fatal disease. Identifying high-risk patients can not only reduce the mortality and morbidity caused by VTE but also reduce the medical tangles caused by sudden death in hospitals. Brandyn D. Lau mentioned that VTE was an adverse event that could be prevented during hospitalization. Risk assessment is the first step in VTE prevention management.¹ In China, Zhenguo Zhai et al. collected 105,723 VTE patients from 2007 to 2016 and found that the hospitalization rate related to VTE increased from 3.2 to 17.5 per

¹ Department of Respiratory and Critical Care Medicine, Beijing Shijitan Hospital, Capital Medical University, Beijing, China

² School of Statistics and Data Science, Nankai University, Tianjin, China

³ Beijing Emergency Medical Center, Beijing, China

⁴ Department of Respiratory and Critical Care Medicine, Beijing Chaoyang Hospital, Capital Medical University, Beijing, China

Corresponding Authors:

Yuanhua Yang, Department of Respiratory and Critical Care Medicine, Beijing Chaoyang Hospital, Capital Medical University, Beijing, 100020, China.
Email: yyh1031@sina.com

Lei Pan, Department of Respiratory and Critical Care Medicine, Beijing Shijitan Hospital, Capital Medical University, Beijing, 100038, China.
Email: panlei@bjsjth.cn



Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (<https://creativecommons.org/licenses/by-nc/4.0/>) which permits non-commercial use,

reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access page (<https://us.sagepub.com/en-us/nam/open-access-at-sage>).

100,000 population.² He also analyzed the data from 2000–2001 to 2010–2011 and showed that the incidence rate of DVT increased from 17.1 per 100,000 to 30.0 per 100,000, PE increased from 3.9 per 100,000 to 8.7 per 100,000, and 51.8% of hospitalized patients were at risk of VTE.³ The Chinese expert consensus on the prevention of VTE recommended the Caprini RAM for surgical patients and Padua RAM for medical patients.⁴ It is well known that Caprini RAM and Padua RAM were derived from western populations, and these two RAM are very complicated, Caprini RAM contains more than 40 risk factors, and Padua RAM has almost 11 risk factors. But there is no unified data for VTE RAM in hospitalized Chinese patients. The aim of this study was to develop and externally validate VTE RAM based on hospitalized Chinese patients.

Methods

Ethical Approval

This study was approved by the Medical ethics committee of Beijing Shijitan Hospital Affiliated with Capital Medical University (No. 2020-2).

Subjects

Development of VTE RAM: We reviewed data from 300 VTE patients and 300 non-VTE patients admitted to Beijing Shijitan (SJT) Hospital from January 2019 to December 2020. **External validation of VTE RAM:** Data from 407 VTE patients and 533 non-VTE patients admitted to Beijing Chaoyang Hospital from October 2021 to March 2022 were collected.

VTE group: The inclusion criteria were as follows: age ≥ 18 years and ≥ 2 days of hospitalization. DVT was confirmed by color Doppler ultrasound and/or venography of the upper and lower limbs, with (or not) PE diagnosed by CT pulmonary angiography (CTPA) or pulmonary ventilation perfusion (V/Q) scanning. The exclusion criteria were as follows: superficial venous thrombosis, anticoagulant (including oral and subcutaneous injection) or thrombolytic drug use at admission or after admission, and incomplete clinical data.

Non-VTE group: We selected patients who were admitted to the same departments during the periods mentioned above. The inclusion criteria were as follows: age ≥ 18 years and ≥ 2 days of hospitalization. Non-DVT patients were diagnosed by color Doppler ultrasound and/or venography of the upper and lower limbs, with non-PE patients confirmed by CTPA or V/Q. The exclusion criteria were as follows: superficial venous thrombosis, anticoagulant (including oral and subcutaneous injection) or thrombolytic drug use at admission or after admission, and incomplete clinical data.

Data collect: We collected some clinical characteristics and the value of D-dimer. The clinical characteristics were as following: age, sex, bed rest, lower limb edema (include

unilateral or bilateral), acute infection, chronic obstructive pulmonary disease, respiratory failure, heart failure, coronary heart disease, nephrotic syndrome, septicemia, cancer,

Table 1. Characteristics of VTE Patients in the Development Group.

Variables	N	Prevalence of VTE (%)	χ^2	P
Age (years)			12.27	<0.001
≤ 60	117	35.04		
>60	483	53.62		
Sex			2.41	0.120
Female	286	53.50		
Male	314	46.82		
Bed rest			7.17	0.007
Yes	160	59.38		
No	440	46.59		
Lower limb edema			7.46	0.006
Yes	91	63.74		
No	509	47.54		
Acute infection			4.96	0.026
Yes	180	57.22		
No	420	46.90		
COPD			6.49	0.011
Yes	62	66.13		
No	538	48.14		
Respiratory failure			12.39	<0.001
Yes	78	69.23		
No	522	47.13		
Heart failure			2.10	0.147
Yes	79	58.23		
No	521	48.75		
Coronary heart disease			5.03	0.025
Yes	203	56.65		
No	397	40.60		
Nephrotic syndrome			1.50	0.220
Yes	25	36.00		
No	575	50.61		
Septicemia			6.90	0.009
Yes	65	66.15		
No	535	48.04		
Cancer			3.50	0.061
Yes	180	56.11		
No	420	47.38		
Thrombocytosis			1.18	0.277
Yes	22	36.36		
No	578	50.52		
CVC			23.93	<0.001
Yes	53	83.02		
No	547	46.80		
VTE history			8.21	0.004
Yes	33	75.76		
No	567	48.50		
D-dimer			110.59	<0.001
$<ULN$	162	25.31		
$\geq 1XULN$ and $\leq 2XULN$	134	32.09		
$>2XULN$	304	71.05		

COPD, chronic obstructive pulmonary disease; CVC, central vein catheterization; ULN, upper limit of normal.

thrombocytosis, central vein catheterization, and VTE history.

Statistical Analyses

1. *Model development*: The risk factors related to VTE were analyzed by logistic regression. The relative risk ratio and 95% confidence interval (CI) were calculated. Each regression coefficient was divided by the minimum coefficient as the score for each item. All of the weighted items were summed as an individual patient's total score. Different risk stratifications were defined according to our pilot study and reference.⁵ The Hosmer–Lemeshow goodness-of-fit test was used to compare the observed and predicted VTE events.
2. *Model validation*: The sensitivity, specificity, and Youden index were analyzed. Based on sensitivity and specificity, an ROC curve was drawn, and the AUC value was defined as the AUC.

Measurement data were expressed as $\bar{x} \pm s$. If the distribution of data was normal, a parametric model was used to calculate the *P* value and confidence interval. For the non-normal distribution of data, the nonparametric rank sum test was used to calculate the *P* value and CI. For discrete features, Fisher's exact test was used to calculate the *p* value. The count data were expressed as percentages (%), and the χ^2 test was used for comparisons between groups. R statistical software (version 3.4.1) was used for all statistical analyses. *P* < 0.05 denotes statistical significance.

Results

VTE RAM (SJT Version) Development

Data from 300 VTE patients and 300 non-VTE patients were collected retrospectively from January 2019 to December 2020, including those from gastrointestinal surgery 67 (11.17%), orthopedics 31 (5.17%), thoracic surgery 53 (8.83%), urologic surgery

8 (1.33%), obstetrics and gynecology 11 (1.83%), cerebral surgery 4 (0.67%), neurology 72 (12%), intensive care unit 68 (11.33%), geriatrics 10 (1.67%), respiratory 154 (25.67%), cardiovascular 32 (5.33%), nephrologic 30 (5%), hematologic 21 (3.5%), and traditional Chinese medicine 6 (1%), rheumatologic and immunologic 2 (0.33%), endocrine 7 (1.17%), oncologic 2 (0.33%), and emergency 22 (3.67%). The characteristics of the patients showed a higher prevalence rate of VTE patients who were experiencing age >60 years, bed rest, lower limb edema, acute infection, COPD, respiratory failure, coronary heart disease, septicemia, central venous catheterization, VTE history and elevated D-dimer. (Table 1)

Logistic regression analysis showed that age, lower limb edema, COPD, central venous catheterization, VTE history, and elevated D-dimer were significantly correlated with the occurrence of VTE. (*P* < 0.05) (Table 2)

The developed VTE RAM (SJT version) was composed of six items, including age >60 years, lower limb edema, COPD, VTE history, CVC, and D-dimer. Each β coefficient was divided by the smallest absolute value of the coefficient as the score for each item (Table 3).

According to the results of our pilot study and the literature,⁶ we stratified VTE RAM (SJT version) according to the cumulative score as follows: 0 low risk; 1 moderate risk; 2–4 high risk; and ≥ 5 highest risk. Based on AUC values of SJT, Caprini and Padua RAMs, the AUC value of SJT RAM (0.75 \pm 0.03) is significantly higher than the value of Padua RAM (0.53 \pm 0.03; *P* < 0.05), SJT RAM (0.75 \pm 0.03) vs Caprini RAM (0.73 \pm 0.03; *P* > 0.05), which showed that the developed model had better predictive ability than Padua RAM for the all retrospective hospitalized patients. SJT RAM and Caprini RAM have a similar predictive ability for all retrospective hospitalized patients (Figure 1).

The overall fitting degree of the model was evaluated by the fitting degree, and the agreement degree between the predicted event and the observed event was evaluated by the Hosmer–Lemeshow (H–L) goodness-of-fit test. In the H–L test, if *p* > 0.05, it is considered that the fitting degree of the model is good, indicating that the agreement between the predicted VTE event and the observed VTE event is high. The H–L test result of our developed VTE RAM (*p* = 0.9987 > 0.05) indicates excellent agreement (Figure 2).

Table 2. Logistic Regression Analysis of VTE Risk Factors.

Characteristic	β	Std. Error	Z value	<i>P</i> value
Age >60 years	0.420	0.250	2.036	0.042
Bed rest	0.194	0.266	0.728	0.466
Lower limb edema	0.298	0.326	1.979	0.048
Acute infection	0.001	0.283	0.004	0.997
COPD	0.488	0.369	2.042	0.041
Respiratory failure	0.335	0.456	0.733	0.463
Coronary heart disease	0.138	0.250	0.554	0.580
Septicemia	0.035	0.461	0.076	0.939
CVC	1.732	0.477	3.623	0.000
VTE history	1.231	0.478	2.592	0.01
D-dimer	0.960	0.122	7.461	0.000

COPD, chronic obstructive pulmonary disease; CVC, central vein catheterization

Table 3. Risk Assessment Model of VTE (SJT Version).

Risk factor	Score
Age >60 years	1
Lower limb edema	1
COPD	2
VTE history	4
CVC	6
D-dimer $\geq 1XULN$ and $\leq 2XULN$	3
D-dimer >2XULN	6

COPD, chronic obstructive pulmonary disease; CVC, central vein catheterization; ULN, upper limit of normal

VTE RAM (SJT Version) External Validation

We analyzed a total of 940 patients for external validation. Based on AUC values of SJT, Caprini, and Padua RAMs, the

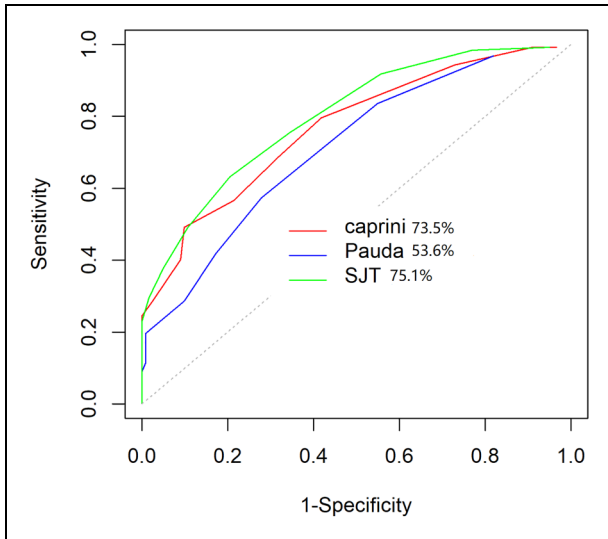


Figure 1. ROC curve of the VTE RAM (SJT version) in all retrospective patients.

AUC value of SJT RAM (0.75 ± 0.03) vs Caprini RAM (0.73 ± 0.03); ($P > 0.05$), and SJT RAM (0.75 ± 0.03) vs Padua RAM (0.72 ± 0.03); ($P > 0.05$), which indicates that the SJT RAM has similar predictive value for all medical patients and surgical patients as Caprini RAM and Padua RAM. (Figure 3)

We analyzed 408 medical patients (204 VTE patients and 204 non-VTE patients) for external validation. the AUC value of SJT RAM (0.82 ± 0.03) is significantly higher than the value of Caprini RAM (0.76 ± 0.04 ; $P < 0.05$), and SJT RAM (0.82 ± 0.03) vs Padua RAM (0.78 ± 0.03 ; $P > 0.05$), which means that the SJT RAM has a much better predictive value than Caprini RAM for medical patients. While SJT RAM and Padua RAM have the similar predictive value for medical patients (Figure 4).

We analyzed 532 surgical patients (203 VTE patients and 329 non-VTE patients) for external validation. The AUC value of SJT RAM (0.72 ± 0.04) is significantly higher than the value of Padua RAM (0.66 ± 0.04 ; $P < 0.05$), SJT RAM (0.72 ± 0.04) vs Caprini RAM (0.72 ± 0.04), which shows that the SJT RAM has better predictive value than Padua RAM for surgical patients. While SJT RAM and Caprini RAM have the similar predictive value for surgical patients (Figure 5).

We found SJT RAM, Caprini RAM, and Padua RAM have a similar sensitivity and specificity and Youden index for all

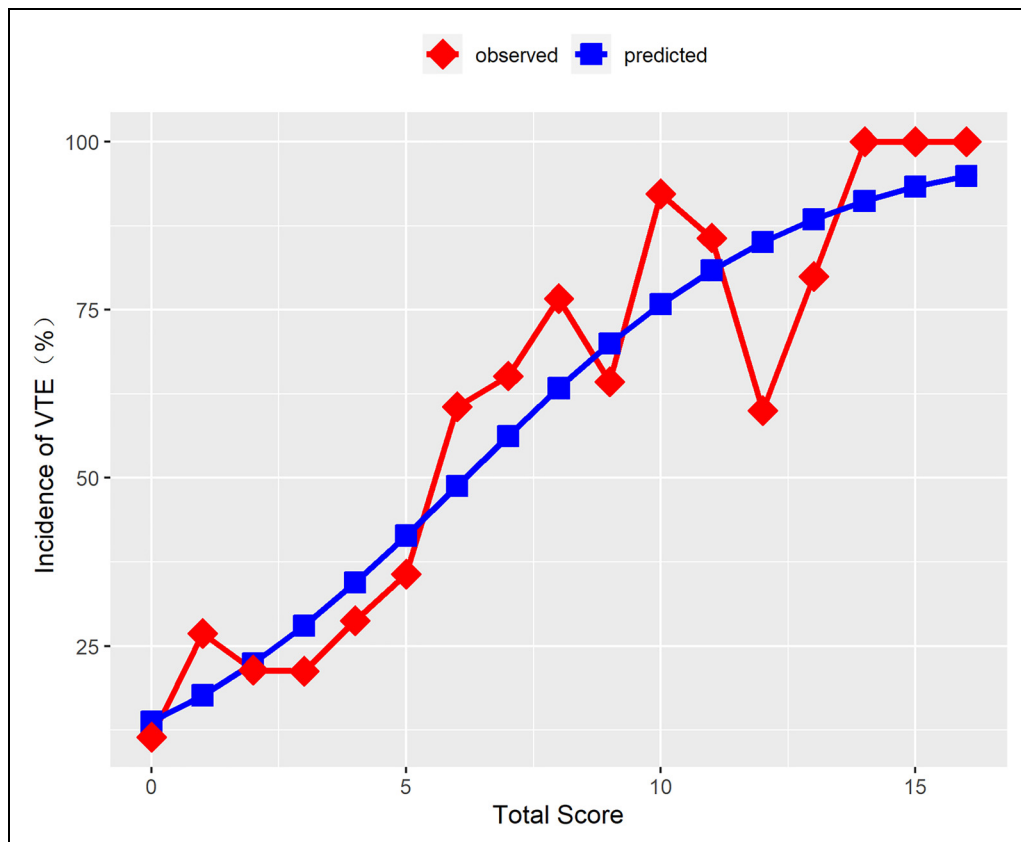


Figure 2. Hosmer-Lemeshow goodness-of-fit test of VTE RAM (SJT version).

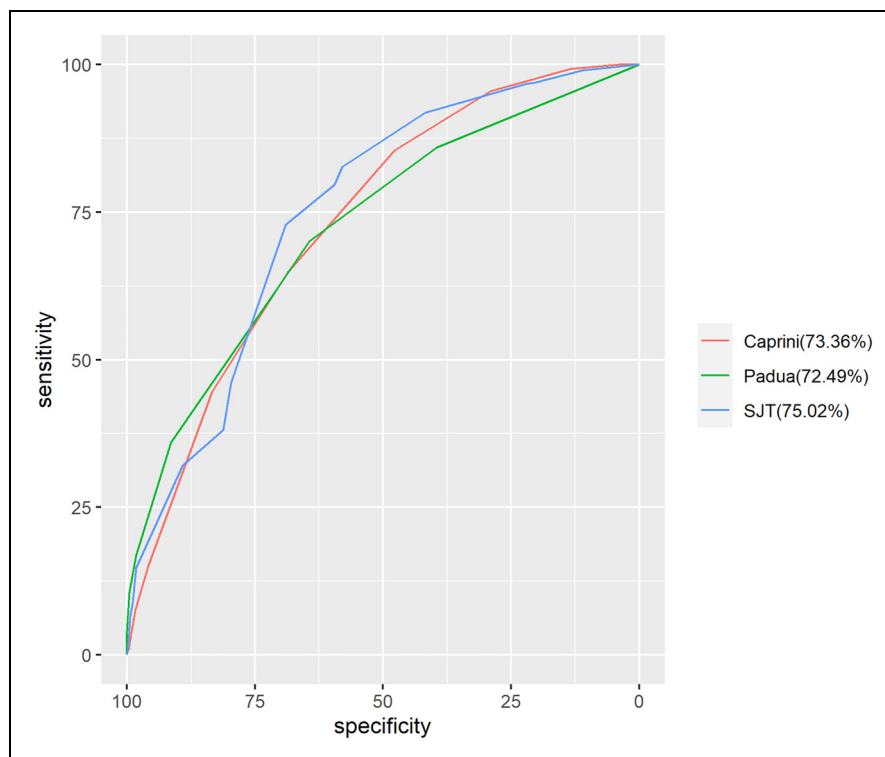


Figure 3. ROC curve of the VTE RAM (SJT version) in all external validation patients.

patients ($P > 0.05$). For internal medicine patients, SJT RAM has a higher sensitivity, specificity, and Youden index than Caprini RAM ($P < 0.05$), while SJT RAM and Padua RAM have a similar sensitivity, specificity, and Youden index ($P > 0.05$). For surgery patients, SJT RAM has a higher sensitivity, specificity, and Youden index than Padua RAM ($P < 0.05$), while SJT RAM and Caprini RAM have a similar sensitivity, specificity, and Youden index ($P > 0.05$) (Table 4).

Discussion

In the United States, each VTE patient needs to spend nearly \$18,000 – \$23,000 every year. VTE events have brought serious economic burdens to society.⁷ It is an important task for VTE prevention management to identify high-risk patients and carry out corresponding prophylaxis. In the United Kingdom, the National Institute for Health and Care Excellence (NICE) analyzed 22 studies and found that nearly 40% of low-risk medical and surgical patients may receive thromboprophylaxis inappropriately.⁸ The Padua RAM and Caprini RAM were constructed by expert consensus, and the International Medical Prevention Registry on Venous Thromboembolism (IMPROVE) score was derived from logistic regression studies.^{9–11} The American College of Chest Physicians (ACCP) recommended Caprini RAM for non-orthopedic surgical patients and Padua RAM for internal medical patients. At that same time, ACCP guidelines emphasize that internal medical patients should use institution-specific VTE risk assessment models.¹² Our VTE RAM was constructed and validated based

on the real-world data of two comprehensive teaching hospitals, not from any RCT research.

This study showed that age, lower limb edema, COPD, CVC, VTE history, and D-dimer elevation were significantly correlated with the occurrence of VTE ($p < 0.05$). It is well known that an increase in age is accompanied by the aging of organs, a decrease in activity, and chronic comorbid diseases. In a review of VTE epidemiology, Richard H. also mentioned that the incidence of VTE at the age of >60 years increased sharply.¹³ Almost all VTE risk assessment models include age, which is easy to obtain and does not require complex calculation formulas. Blondon et al.¹⁴ finished a prospective study to compare whether the current VTE risk assessment models were better than the age model that had age as the only predictor. The results demonstrated that the age model was not significantly different from the current Caprini RAM, Padua RAM, and IMPROVE score ($P = 0.266$). Lower limb edema is a common clinical symptom and sign of VTE, and it was proven to be moderate-level evidence of VTE (or 1.88; 95% CI, 1.23–2.90).¹⁵ COPD has become the fifth leading cause of death worldwide.¹⁶ Harenberg et al.¹⁷ found that even COPD in the stable period will be one of the main causes of VTE. A Spanish retrospective study compared the incidence rate of PE and mortality during hospitalization between COPD and non-COPD patients. They found that the incidence rate and mortality of PE patients with COPD were significantly higher than those without COPD.¹⁸ In the process of developing the model (SJT version), CVC was associated with the occurrence of VTE. Bo et al.¹⁹ proved that the incidence of

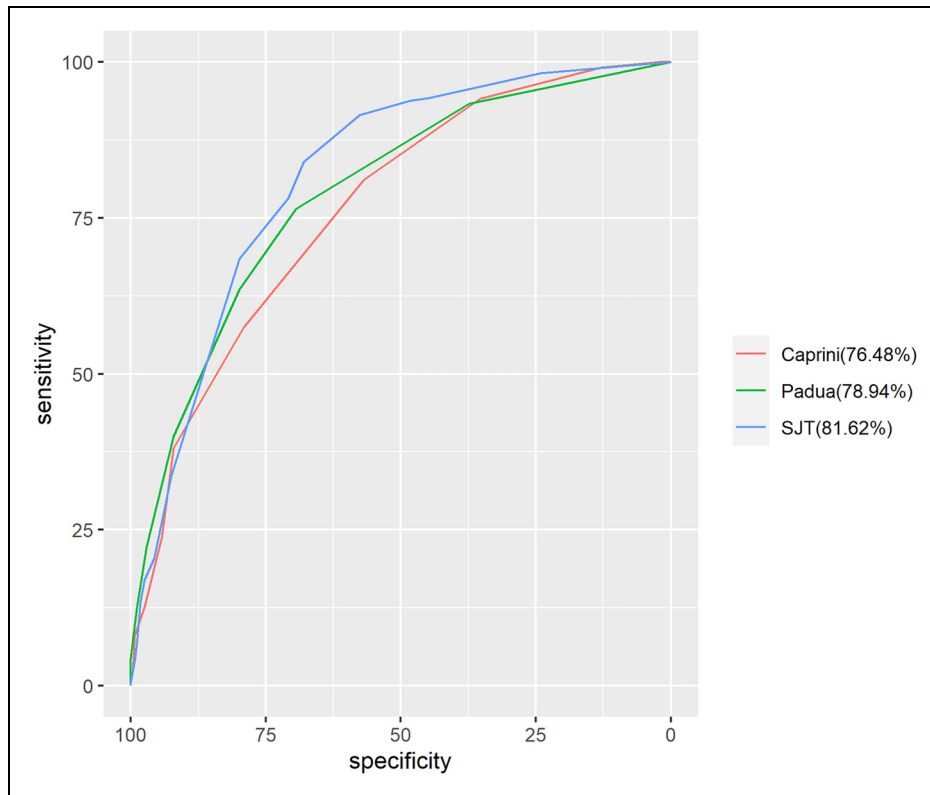


Figure 4. ROC curve of the VTE RAM (SJT version) in medical patients.

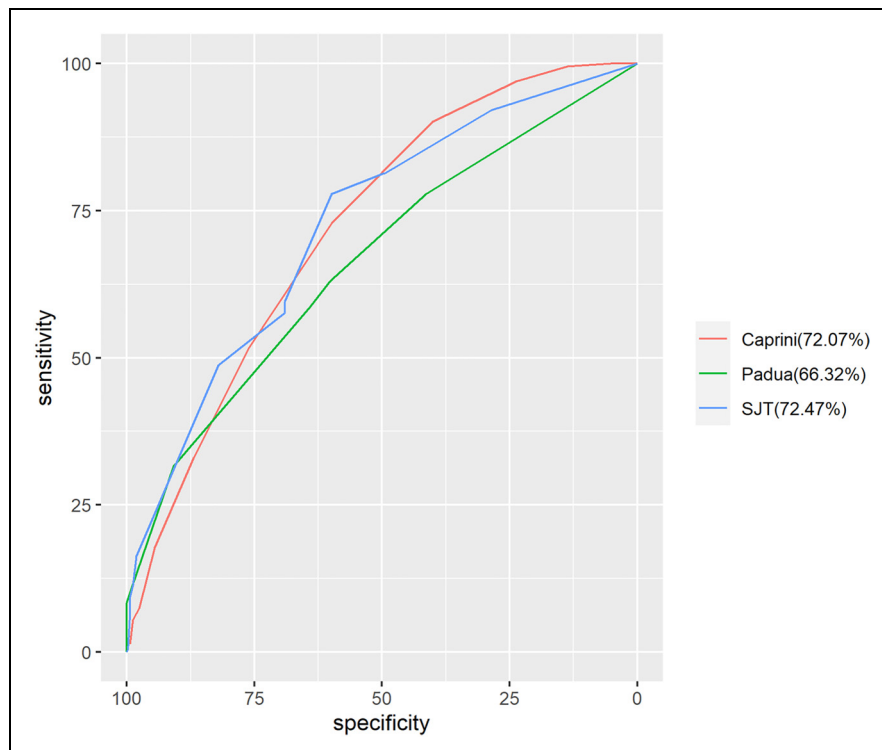


Figure 5. ROC curve of the VTE RAM (SJT version) in surgical patients.

Table 4. Comparison of Different RAMs in External Groups.

	RAM	Sensitivity	Specificity	Youden Index
All Patients	Caprini	0.648	0.687	0.335
	Padua	0.701	0.644	0.345
	SJT	0.729	0.690	0.419
	P Value	>0.05	>0.05	>0.05
Internal medicine patients	Caprini	0.764	0.568	0.38
	Padua	0.812	0.694	0.459
	SJT	0.840	0.680	0.520
	P Value	<0.05 ^a	<0.05 ^a	<0.05 ^a
Surgery patients	Caprini	0.729	0.599	0.328
	Padua	0.631	0.402	0.232
	SJT	0.778	0.599	0.377
	P Value	<0.05 ^b	<0.05 ^b	<0.05 ^b

RAM, risk assessment model; SJT, Shijitan
a, SJT vs Caprini; b, SJT vs Padua.

CVC-related VTE was 2%–11%, and the number was higher in cancer patients. Catheter-related VTE (CRT) accounts for approximately 10% of DVT cases. Many factors lead to CRT, such as aging, catheter retention time, catheter/vein >0.45, type and material. The catheter activated the coagulation pathway triggered by tissue factors and promoted blood coagulation. The American Society of Hematology guideline recommends that CRT patients should receive anticoagulation until the catheter is removed.²⁰ In the prospective study of Joffe et al.,²¹ only 3.6%–4.3% of CRTs were symptomatic. A peripherally inserted central catheter (PICC) has a higher probability of CRT due to a damaged local vascular wall and slow blood flow.^{22, 23} CVC was proven to be an independent risk factor for VTE, and it has nothing to do with the location of CVC.²⁴

We incorporated the VTE history into the VTE RAM (SJT version), which is another important risk factor for VTE.²⁵ The recurrence rate of VTE within 5 years in patients with a previous history of VTE was almost 10%–30%.²⁶ A retrospective cohort study involving 9472 trauma patients revealed that there were more patients with a VTE history than those without a VTE history (2.4% vs 0.1%; $p < 0.001$).²⁷ In 2019, a case-control study reported that the probability of VTE recurrence in surgical patients with a VTE history was 6-fold higher than that in those without a VTE history.²⁸ What makes our VTE RAM different from Caprini RAM and Padua RAM was that we included D-dimer. There is no doubt that D-dimer is closely related to VTE. Patients at high VTE risk with increasing D-dimer could benefit from extended anticoagulation.²⁹ Some domestic studies have tried to combine the Caprini RAM and D-dimer, and the combined RAM has a good predictive ability for ICU high-risk VTE patients.³⁰ In the IMPROVEDD study, two points were added to the IMPROVE score if D-dimer was more than 2-fold upper limit of normal, and the IMPROVEDD score was found to improve VTE risk stratification and the predictive ability of VTE through 77 days in acute medical inpatients.³¹ Eichinger et al.³² also incorporated D-dimer into the IMPROVE score and discovered that it can screen for recurrence of VTE after stopping anticoagulation. In our study, considering

the different lab methods and normal value range of D-dimer in every hospital, we did not add a fixed value of D-dimer, and only the level of elevation was considered, which was in agreement with the above IMPROVEDD study.

In clinical practice, a simpler VTE risk assessment model will result in better compliance for health care providers. The VTE RAM (SJT version) included six risk factors (age, lower limb edema, COPD, CVC, VTE history, and D-dimer) that were easily available at admission. In external validation, SJT RAM and Caprini RAM have similar predictive value for surgical patients. And SJT RAM and Padua RAM also have similar predictive value for medical patients. Our previous research also confirmed that Caprini RAM for surgical patients and Padua RAM for medical patients among Chinese hospitalized patients.³³ At present, there are few VTE risk assessment models for general hospitalized patients, especially in China. Many teams constructed VTE risk assessment models for specific diseases based on the data of their institutions. Wang and colleagues³⁴ collected data from 81,505 surgical inpatients in Southwest Hospital of China from January 1, 2019, to June 18, 2021, and built the SW model. This model internally verified that the predictive ability of VTE in surgical patients was better than that of the Caprini RAM. Lok et al.³⁵ developed a VTE risk assessment model including five risk factors (including overweight, advanced maternal age, multiple priority, obesity, and primary postpartum hemorrhage) by analyzing 859 Chinese obstetrics and gynecology patients. This model avoided inappropriate anticoagulation. Yao et al.³⁶ established VTE risk assessment models including age ≥ 69 years, preoperative plasma D-dimer ≥ 0.49 mg/L, stage IV cancer and transfusion. The AUC of this model was 0.769, while that of the Caprini RAM was 0.656. Tian et al.³⁷ of Chaoyang Hospital built a VTE risk assessment model for patients undergoing thoracic surgery. Qu et al.³⁸ simplified the Caprini RAM in 2015 and built the gynecological Caprini (G-Caprini) RAM for patients undergoing gynecological surgery. The G-caprini RAM has six risk factors: varicose veins, bed rest ≥ 48 h, length of operation ≥ 3 h, latitude, hypertension, and age ≥ 50 years. It effectively identified low-risk VTE patients. Some constructed risk assessment models for cancer patients, Marlise Alexander constructed VTE RAM, which is applicable to non-small cell carcinoma (NSCLC) patients, including chemotherapy, D-dimer, and fibrinogen.³⁹ Li et al.⁴⁰ built and validated a VTE risk assessment model for lung cancer, including cancer type, age, sex, bed rest, CVC, and anticancer treatment. Muñoz Martín et al.⁴¹ built a clinical-genetic risk model for predicting VTE events in patients with cancer. This risk score can better identify cancer patients with VTE risk than the Khorana score. In addition, there were some VTE risk assessment models by novel methods. Yang y constructed a VTE risk assessment model for tumor patients through machine learning (ML) technologies, which also has better predictive ability than Padua RAM (AUC 0.973 ± 0.006 vs 0.791 ± 0.022) ($p < 0.001$).⁴² Ahmad built a VTE recurrence risk assessment model by detecting single-nucleus polymers (SNPs). This eight-gene mutation model was revealed to have good predictive

ability for the recurrence of VTE in men, especially those without obvious risk factors.⁴³

The similarities between SJT RAM and Caprini RAM are that they include age, lower limb edema, COPD, VTE history, and CVC. Age and VTE history are the common items of SJT RAM and Padua RAM, which are easily available at admission. The major difference between SJT RAM and Caprini RAM and Padua RAM is that our model includes D-dimer, while the other two RAMs do not. Another difference is the number of RAM, since Caprini RAM has nearly forty risk factors and Padua RAM has eleven risk factors. Nevertheless, VTE RAM (SJT version) has only six risk factors, so physicians and nurses will save much time in assessing VTE risk for hospitalized patients. Therefore, the working burden of medical staff will be reduced. In addition, our VTE RAM (SJT version) was proven to be available for all hospitalized patients rather than specific diseases, as illustrated above. Therefore, our model is applicable to a wider range of inpatients.

The limitation of our study is that the SJT RAM does not include surgical items such as anesthesia time and surgical operation types, which may be the reason why the predictive ability of surgical patients is lower than that of internal medical patients. However, the risk factors we included are easily obtained information at admission. Fewer risk factors are included, less time will be spent, and the compliance of medical staff will also be higher. According to a previous study, most patients with VTE were diagnosed within 3 months after admission, and 67% of them were confirmed within 1 month after admission.⁴⁴ Hospitalized patients need to be dynamically assessed during admission, transfer, and discharge. One study found that VTE risk stratification was different on Day 1 and Day 3 after admission (4.7 ± 1.7 vs 4.2 ± 1.8 ; $p = .008$).⁴⁵ Therefore, it is particularly important to carry out dynamic evaluations of inpatients. In the next step, we will study the weights of anesthesia time and surgical operation types and add these specific surgical items to this VTE RAM (SJT version), which is applicable to surgical patients due to surgery, when the patients' risk status will change during hospitalization.

As VTE prevention management has received increasing attention in China, more evidence about VTE risk assessment models for hospitalized Chinese patients is needed. The SJT RAM we built based on institution inpatients was proven effective through external validation. It can help screen patients with VTE risk, and improve awareness of VTE risk prevention. In the future, we plan to conduct a clinical study on VTE prevention according to the risk stratification of SJT and the bleeding risk of patients. If the patient has VTE risk and high bleeding risk, the patient should receive mechanical prevention, then dynamically assess the patient's VTE risk and bleeding risk. If the patient still has the VTE risk, but the risk of bleeding is low, the patient should receive drug prophylaxis. VTE-related serious complications and corresponding medical expenses will be reduced.


Declaration of Conflicting Interests


The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.


Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iDs

Xiaolan Chen  <https://orcid.org/0000-0002-8071-4286>

Yong Wang  <https://orcid.org/0000-0002-2815-2298>

Yuanhua Yang  <https://orcid.org/0000-0003-0293-6737>

Supplemental Material

Supplemental material for this article is available online.

References

1. Lau BD, Streiff MB, Pronovost PJ, Haut ER. Venous thromboembolism quality measures fail to accurately measure quality. *Circulation*. 2018;137(12):1278-1284.
2. Zhang Z, Lei J, Shao X, et al. Trends in hospitalization and in-hospital mortality from VTE, 2007 to 2016, in China. *Chest*. 2019;155(2):342-353.
3. Zhai Z, Kan Q, Li W, et al. VTE Risk profiles and prophylaxis in medical and surgical inpatients: The identification of Chinese hospitalized Patients' risk profile for venous thromboembolism (DissoLVE-2)-A cross-sectional study. *Chest*. 2019;155(1):114-122.
4. Wang C, Zhai ZG. Focus on the prevention, treatment and management of venous thromboembolism: What can we learn from the 9th ACCP guidelines. *Zhonghua Yi Xue Za Zhi*. 2013;93(24):1857-1859.
5. Xiaoyun L, Fuxian Z. Validation of the caprini risk assessment model for venous thromboembolism in a general hospital. *Zhonghua Yi Xue Za Zhi*. 2017, 24(97): 1875-1877.
6. Datta A, Matlock MK, Le Dang N, et al. 'Black box' to 'conversional' machine learning: Ondansetron reduces risk of hospital-acquired venous thromboembolism. *IEEE J Biomed Health Inform*. 2021;25(6):2204-2214.
7. Grosse SD, Nelson RE, Nyarko KA, Richardson LC, Raskob GE. The economic burden of incident venous thromboembolism in the United States: A review of estimated attributable healthcare costs. *Thrombosis Res* 2016; 137(1):3-10.
8. Deheinzelin D, Braga A, Martins L, et al. Incorrect use of thromboprophylaxis for venous thromboembolism in medical and surgical patients: Results of a multicentric, observational and cross-sectional study in Brazil. *J Thromb Haemostasis* 2006; 4(6):1266-1270.
9. Barbar S, Noventa F, Rossetto V, et al. A risk assessment model for the identification of hospitalized medical patients at risk for venous thromboembolism: The Padua prediction score. *J Thromb Haemost*. 2010;8(11):2450-2457.
10. Caprini JA, Arcelus JI, Hasty JH, Tamhane AC, Fabrega F. Clinical assessment of venous thromboembolic risk in surgical patients. *Semin Thromb Hemost*. 1991;17(Suppl 3):304-312. PMID: 1754886.
11. Spyropoulos AC, Anderson FA, FitzGerald G, et al. Predictive and associative models to identify hospitalized medical patients at risk for VTE. *Chest*. 2011;140(3):706-714.
12. Tapson VF, Decousus H, Pini M, et al. Venous thromboembolism prophylaxis in acutely ill hospitalized medical patients: Findings

- from the international medical prevention registry on venous thromboembolism. *Chest* 2007; 132(3): 936-945.
13. White RH. The epidemiology of venous thromboembolism. *Circulation*. 2003; 107(23 suppl 1):14-18.
 14. Blondon M, Spirk D, Kucher N, et al. Comparative performance of clinical risk assessment models for hospital-acquired venous thromboembolism in medical patients. *Thromb Haemost*. 2018;118(1):82-89.
 15. Grant PJ, Greene MT, Chopra V, Bernstein SJ, Hofer TP, Flanders SA. Assessing the caprini score for risk assessment of venous thromboembolism in hospitalized medical patients. *Am J Med*. 2016;129(5):528-535.
 16. Halpin DMG, Criner GJ, Papi A, et al. Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease. The 2020 GOLD science committee report on COVID-19 and chronic obstructive pulmonary disease. *Am J Respir Crit Care Med*. 2021;203(1):24-36.
 17. Harenberg J, Verhamme P. The dangerous liaisons between chronic obstructive pulmonary disease and venous thromboembolism. *Thromb Haemost* 2020;120(3):363-365.
 18. Bertoletti L, Couturaud F. COPD Is not only one of the several VTE risk factors. *Eur J Intern Med*. 2021;84(2):14-15.
 19. Bo H, Li Y, Liu G, et al. Assessing the risk for development of deep vein thrombosis among Chinese patients using the 2010 caprini risk assessment model: A prospective multicenter study. *J Atheroscler Thromb*. 2020;27(8):801 – 8808.
 20. Citla Sridhar D, Abou-Ismaïl MY, Ahuja SP. Central venous catheter-related thrombosis in children and adults. *Thromb Res*. 2020;187(3):103-112.
 21. Joffe HV, Kucher N, Tapson VF, et al. Upper-extremity deep vein thrombosis: A prospective registry of 592 patients. *Circulation*. 2004;110(12):1605-1611.
 22. King DR, Cohn SM, Feinstein AJ, Proctor KG. Systemic coagulation changes caused by pulmonary artery catheters: Laboratory findings and clinical correlation. *J Trauma*. 2005;59(4):853-857.
 23. Ryan ML, Thorson CM, King DR, et al. Insertion of central venous catheters induces a hypercoagulable state. *J Trauma Acute Care*. 2012;73(2):385-390.
 24. Viarasilpa T, Panyavachiraporn N, Jordan J, et al. Venous thromboembolism in neurocritical care patients. *J Intensive Care Med*. 2020;35(11):1226-1234.
 25. Saber W, Moua T, Williams EC, et al. Risk factors for catheter-related thrombosis (CRT) in cancer patients: A patient-level data (IPD) meta-analysis of clinical trials and prospective studies. *J Thromb Haemost*. 2011;9(2):312-319.
 26. Tadesse TA, Kedir HM, Fentie AM, Abiye AA. Venous thromboembolism risk and thromboprophylaxis assessment in surgical patients based on caprini risk assessment model. *Risk Manag Healthc Policy*. 2020;13(10):2545-2552.
 27. Boo S, Oh H, Hwang K, Jung K, Moon J. Venous thromboembolism in a single Korean trauma center: Incidence, risk factors, and assessing the validity of VTE diagnostic tools. *Yonsei Med J*. 2021;62(6):520-527.
 28. Nemeth B, Lijfering WM, Nelissen RGHH, Schipper IB, Rosendaal FR, le Cessie S. Risk and risk factors associated with recurrent venous thromboembolism following surgery in patients with history of venous thromboembolism. *JAMA Netw Open*. 2019;2(5):e193690.
 29. Spyropoulos AC, Lipardi C, Xu J, et al. Modified IMPROVE VTE risk score and elevated D-dimer identify a high venous thromboembolism risk in acutely ill medical population for extended thromboprophylaxis. *TH Open*. 2020;4(1):e59-e65.
 30. Fu Y, Liu Y, Chen S, Jin Y, Jiang H. The combination of caprini risk assessment scale and thrombotic biomarkers to evaluate the risk of venous thromboembolism in critically ill patients. *Medicine (Baltimore)*. 2018;97(47):e13232.
 31. Gibson CM, Spyropoulos AC, Cohen AT, et al. The IMPROVEDD VTE risk score: Incorporation of D-dimer into the IMPROVE score to improve venous thromboembolism risk stratification. *TH Open*. 2017;1(1):e56-e65.
 32. Eichinger S, Heinze G, Jandek LM, Kyrle PA. Risk assessment of recurrence in patients with unprovoked deep vein thrombosis or pulmonary embolism: The Vienna prediction model. *Circulation* 2010;121(14):1630-1636.
 33. Chen X, Pan L, Deng H, et al. Risk assessment in Chinese hospitalized patients comparing the Padua and caprini scoring algorithms. *Clin Appl Thromb Hemost*. 2018;24(9_suppl):127S – 1135S.
 34. Wang P, Wang Y, Yuan Z, et al. Venous thromboembolism risk assessment of surgical patients in southwest China using real-world data: Establishment and evaluation of an improved venous thromboembolism risk model. *BMC Med Inform Decis Mak*. 2022;22(1):59.
 35. Lok WY, Kong CW, To WWK. A local risk score model for venous thromboembolism prophylaxis for caesarean section in Chinese women and comparison with international guidelines. *Taiwan J Obstet Gynecol*. 2019;58(4):520-525.
 36. Yao J, Lang Y, Su H, Dai S, Ying K. Construction of risk assessment model for venous thromboembolism after colorectal cancer surgery: A Chinese single-center study. *Clin Appl Thromb Hemost*. 2022;28(10):1-7.
 37. Tian B, Li H, Cui S, Song C, Li T, Hu B. A novel risk assessment model for venous thromboembolism after major thoracic surgery: A Chinese single-center study. *J Thorac Dis*. 2019;11(5):1903-1910.
 38. Qu H, Li Z, Zhai Z, et al. Predicting of venous thromboembolism for patients undergoing gynecological surgery. *Medicine (Baltimore)* 2015;94(39):e1653.
 39. Alexander M, Ball D, Solomon B, et al. Dynamic thromboembolic risk modelling to target appropriate preventative strategies for patients with non-small cell lung cancer. *Cancers (Basel)*. 2019;11(1):50.
 40. Li Z, Zhang G, Zhang M, Mei J, Weng H, Peng Z. Development and validation of a risk score for prediction of venous thromboembolism in patients with lung cancer. *Clin Appl Thromb Hemost*. 2020;26(2):1-10.
 41. Muñoz Martín AJ, Ortega I, Font C, et al. Multivariable clinical-genetic risk model for predicting venous thromboembolic events in patients with cancer. *Br J Cancer*. 2018;118(8):1056-1061.
 42. Yang Y, Wang X, Huang Y, Chen N, Shi J, Chen T. Ontology-based venous thromboembolism risk assessment model developing from medical records. *BMC Med Inform Decis Mak*. 2019;19(Suppl 4):151.
 43. Ahmad A, Sundquist K, Palmér K, Svensson PJ, Sundquist J, Memon AA. Risk prediction of recurrent venous thromboembolism:

- A multiple genetic risk model. *J Thromb Thrombolysis*. 2019;47(2):216-226.
44. Spencer FA, Lessard D, Emery C, Reed G, Goldberg RJ. Venous thromboembolism in the outpatient setting. *Arch Intern Med*. 2007; 167 (14): 1471-1475.
45. Chaudhary R, Kirchoff R, Kingsley T, Newman JS, Houghton DE, McBane RD2nd. Venous thromboembolism prophylaxis: Need for continuous assessment due to changes in risk during the same hospitalization. *Mayo Clin Proc Innov Qual Outcomes*. 2020;4(2):170-175.