The Validation and Modification of the Caprini Risk Assessment Model for Evaluating Venous Thromboembolism after Joint Arthroplasty

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Abstract

Background The Caprini risk assessment model (RAM) is the most commonly used tool for evaluating venous thromboembolism (VTE) risk, a high score for arthroplasty can result in patients being classified as high risk for VTE. Therefore, its value in post-arthroplasty has been subject to debate.

Methods Retrospective data were collected from patients who underwent arthroplasty between August 2015 and December 2021. The study cohort included 3,807 patients, all of whom underwent a thorough evaluation using Caprini RAM and vascular Doppler ultrasonography preoperatively.

Results A total of 432 individuals (11.35%) developed VTE, while 3,375 did not. Furthermore, 32 (0.84%) presented with symptomatic VTE, while 400 (10.51%) were detected as asymptomatic. Additionally, 368 (9.67%) VTE events occurred during the hospitalization period, and 64 (1.68%) cases were detected during postdischarge follow-up. Statistical analysis revealed significant differences between the VTE and non-VTE groups in terms of ages, blood loss, D-dimer, body mass index >25, visible varicose veins, swollen legs, smoking, history of blood clots, broken hip, percent of female, hypertension, and knee joint arthroplasty ($p < 0.05$). The Caprini score was found to be significantly higher in the VTE group (10.10 ± 2.23) compared with the non-VTE group (9.35 ± 2.14) ($p < 0.001$). Furthermore, there was a significant correlation between the

Keywords
- Caprini risk assessment model (RAM)
- venous thromboembolism (VTE)
- arthroplasty

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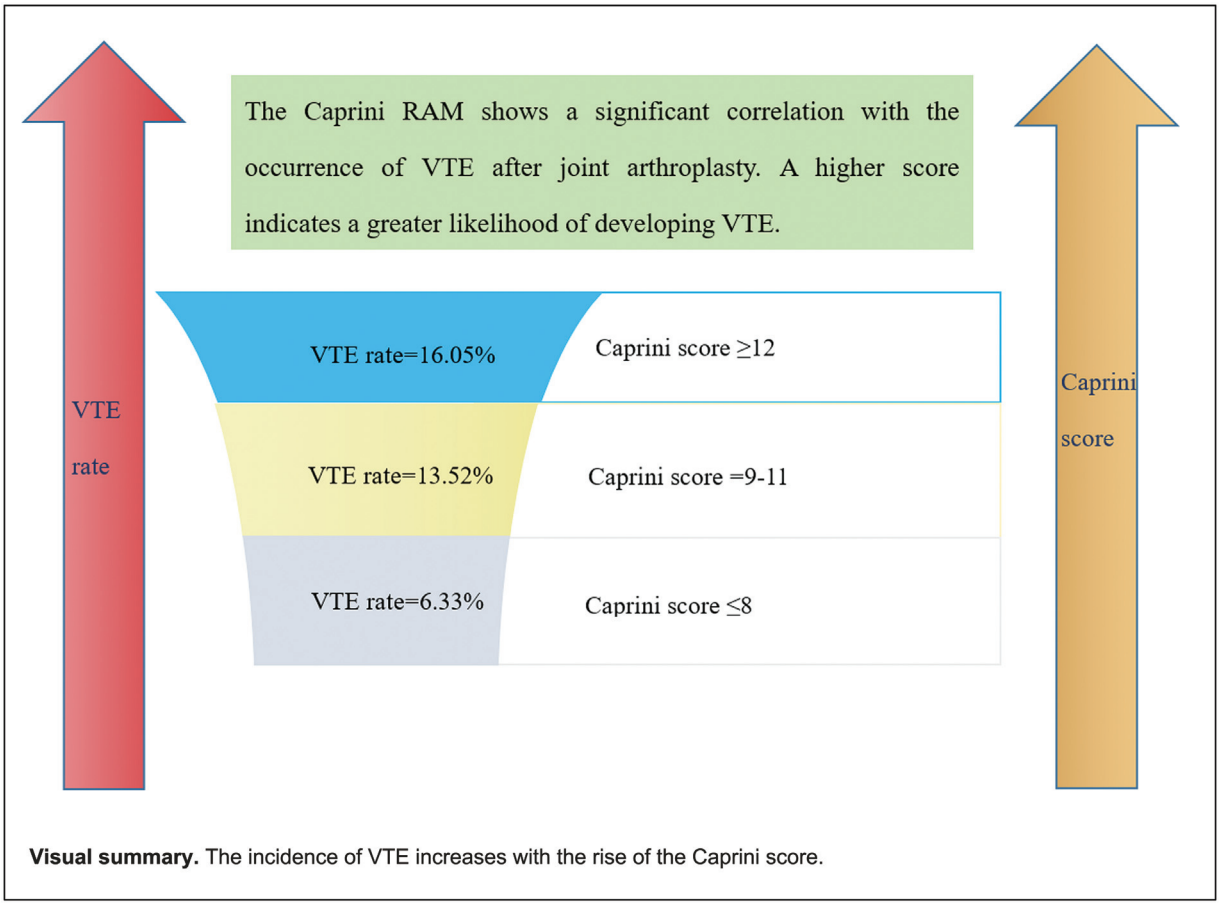


Visual summary. The incidence of VTE increases with the rise of the Caprini score.

incidence of VTE and the Caprini score ($r = 0.775$, $p = 0.003$). Patients with a score ≥9 are at a high-risk threshold for postoperative VTE.

Conclusion The Caprini RAM shows a significant correlation with the occurrence of VTE. A higher score indicates a greater likelihood of developing VTE. The score ≥9 is at particularly high risk of developing VTE.

Introduction

Venous thromboembolism (VTE) is a serious complication of total joint arthroplasty (TJA), which includes deep vein thrombosis (DVT) and pulmonary embolism (PE). In the past, the incidence of VTE among TJA patients without prophylaxis was reported to be nearly 50%.[1] Despite the implementation of various VTE prevention measures, such as the utilization of pneumatic pumps, elastic socks, and anti-coagulation drugs,[2,3] it is important to acknowledge that some patients may still experience a clinically symptomatic DVT, estimated to occur in 0.3 to 4.3% of cases.[4] However, if all patients are screened after TJA, the incidence of DVT is in the range of 15 to 20%.[5] While many cases of DVT are asymptomatic, they have the potential to progress to PE, which can be fatal if left untreated.[6]

In the management of DVT, prevention holds greater significance than cure. To assess the risk of thrombosis in patients, various scoring scales have been developed, such as the Caprini scale, Padua scale, modified Wells scale, revised Geneva scale, and Michigan risk score.[7–11] Among these, the Caprini scale is the most commonly used and regarded as the most accurate for many patients.[12,13] Orthopaedic surgery patients are at a heightened risk of thrombosis, prompting many specialists to establish guidelines for prevention. These guidelines typically advise on medication, devices, and other preventative measures to minimize the risk of DVT. In China, the Caprini model has been incorporated into the national guidelines for VTE prevention and treatment.[14] The Caprini risk assessment model (RAM) is not limited to orthopaedic surgery but can also be applied to other surgical procedures such as gynecological, general, and thoracic surgeries.[15–17]

The Caprini RAM is a thrombotic risk stratification tool that was initially published in 1991.[18] This model was designed based on both clinical experience and medical evidence, making it an effective, simple, feasible, economical,

and practical tool for predicting the risk of VTE. The Caprini score was validated in a surgical population by incorporating inherent risk factors and surgical-specific risk factors to accurately stratify the risk level of DVT. Compared with other RAMs, the Caprini model has demonstrated its advantages in terms of accuracy, ease of use, and practicality.[19] The updated Caprini RAM (2013 version), released in 2019, provides a more comprehensive, consistent, and effective method for risk stratification and prophylaxis selection to prevent venous thrombosis. The study incorporates certain relevant components of the Caprini score, with the complete scoring system described in ►**Fig. 1** and reference provided.[20] This version incorporates new risk factors and score system modifications that better align with current clinical practice. Numerous studies have demonstrated the effectiveness of the Caprini model in predicting VTE risk and guiding prophylaxis selection in different surgical procedures, including arthroplasty.[21–23] Nevertheless, certain studies have presented differing perspectives on the Caprini model's usefulness in patients undergoing TJA. The primary reason for this is that a score of 5 or higher on the Caprini model is deemed high risk. However, the score for joint arthroplasty surgery is already 5, rendering it ineffective in providing a valuable risk warning.[24] However, the University of Michigan defines a score greater than 8 as "super-high risk."[25] It is important to note that patients undergoing arthroplasty generally tend to be older and have higher baseline scores. As a result, the majority of postoperative patients in this population have Caprini scores exceeding 8 points. Krauss et al's study defined Caprini score $\geq$10 as a high-risk factor for joint arthroplasty; however, they only focused on PE and symptomatic DVT without performing routine lower extremity ultrasound examination.[23] Additionally, the number of VTE cases was limited to just eight patients, which means their conclusion requires further validation with more data. To achieve a more accurate verification of its effectiveness, we analyzed 7 years' worth of VTE data related to joint arthroplasty. The results of our analysis are presented below.

Patients and Methods

The Ethics Committee in Clinical Institution of Nanjing Drum Tower Hospital approved the collection of retrospective data from patients who underwent various joint arthroplasties, such as TKA (total knee arthroplasty), UKA (unicompartmental knee arthroplasty), THA (total hip arthroplasty), revision TKA, and revision THA. These data were collected between August 2015 and December 2021. Patients were excluded from the study if they had incomplete basic information, did not undergo preoperative or postoperative lower extremity vascular color Doppler ultrasound examination, had severe renal or organ insufficiency, periprosthetic joint infections, postoperative joint dislocation, blood diseases, or were lost to follow-up after the surgery and could not be contacted through any means.

As part of our study on VTE prevention and cure, we created a thrombosis database that consisted of over 4,000 adult patients who underwent arthroplasty surgery. The data provided by it have been published in numerous national and international journals. They encompass a wide range of information, including patients' demographic characteristics, medical history (such as surgical, thrombosis, medication, and tumor history), as well as surgical details such as operation time, bleeding volume, and blood transfusion. Additionally, preoperative and postoperative laboratory tests and lower extremity venous ultrasound results were also included. We designed a retrospective, observational study using the existing database.

Two sonographers conducted routine ultrasounds of the bilateral lower limb using the SonoSite M-Turbo machine one day before the operation and 3 to 5 days after the operation. A total of 4,313 patients who underwent hip or knee arthroplasty were included in the study, while 149 patients with incomplete information were excluded. To ensure the accuracy of our study, we conducted preoperative lower extremity vascular ultrasounds on all surgical patients. After excluding 357 patients with preoperative VTE, a total of 3,807 patients were included in the study, as illustrated in ►**Fig. 2**. Our analysis included symptomatic VTE, which encompasses both symptomatic DVT and PE. Specifically, symptomatic DVT is characterized by symptoms such as swelling, pain, tenderness, warmth, or color change in the affected area. The diagnosis of PE is based on the patient's presentation of sudden chest tightness, chest pain, breathlessness accompanied by rapid breathing, peripheral blood oxygen saturation suddenly dropping below 90%, or sudden unexplained increase in heart rate, confirmed by pulmonary angiography.

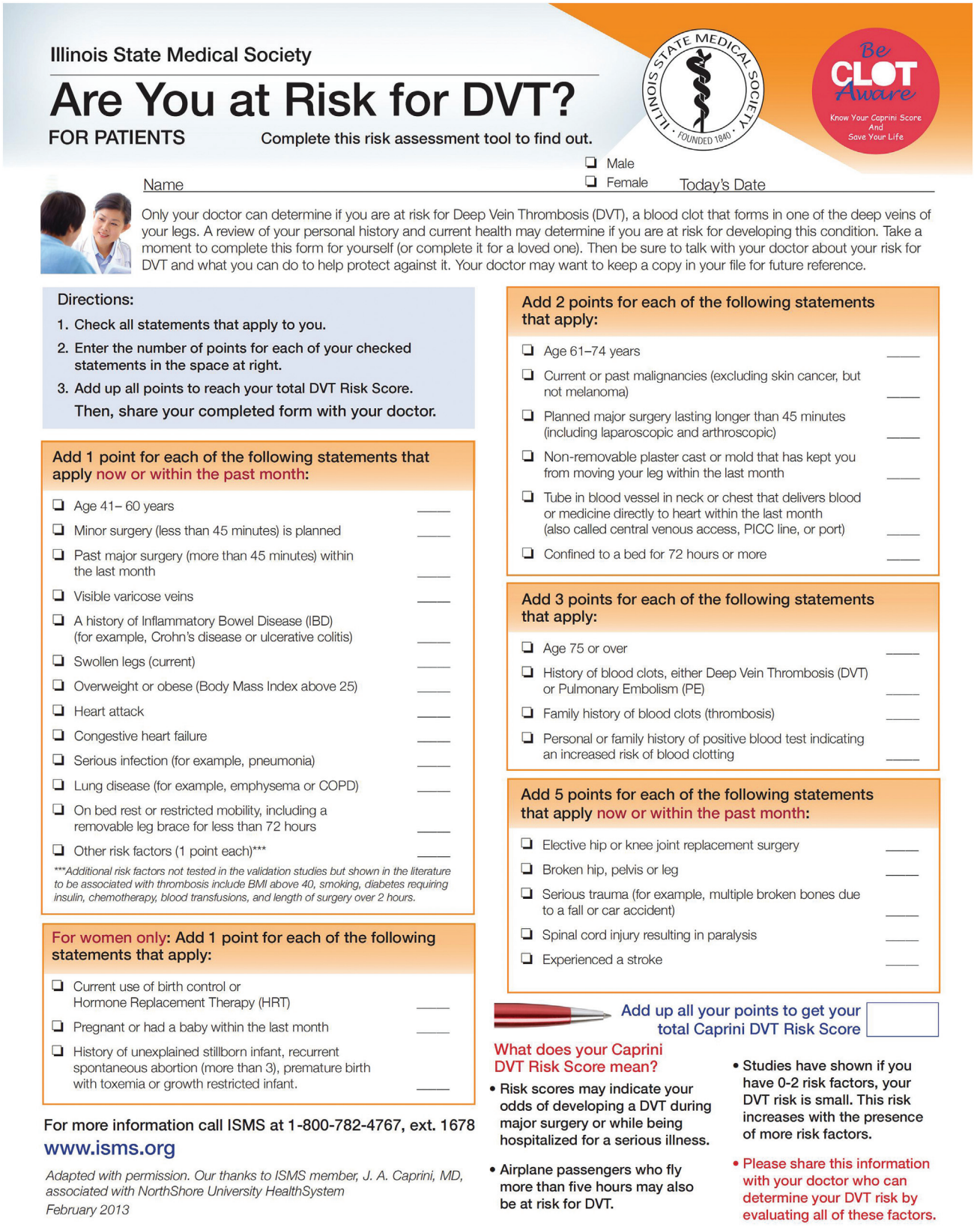
The Caprini RAM edition 2013 was utilized in this study. All data were collected and assessed by dedicated persons. In addition, face-to-face interaction was found to be more accurate for assessing the Caprini RAM than relying solely on electronic medical records.[26]

Anticoagulation Protocol

Patients with femoral neck fracture or intertrochanteric fracture were administered either rivaroxaban or low-molecular-weight heparin upon admission, unless they had a contraindication to anticoagulation therapy. Additionally, all patients received rivaroxaban or low-molecular-weight heparin and underwent rhythmic compression of the bilateral lower limbs with a pressure pump to prevent DVT starting from the first postoperative night.

Statistical Analysis

All demographic data were analyzed using descriptive statistics. The *t*-test was used to analyze age, body mass index (BMI), operation time, blood loss, D-dimer, and Caprini score. A chi-square test was performed to determine the frequency of DVT according to gender, hypertension, diabetes, malignancy, and smoking history. The study involved plotting a receiver operating characteristic (ROC) curve, which was used to calculate the area under the curve (AUC) and determine the optimal cutoff value for the binary classifier. Statistical significance was set at a *p*-value of less than



Illinois State Medical Society

Are You at Risk for DVT?

FOR PATIENTS Complete this risk assessment tool to find out.

Be CLOT Aware — Know Your Caprini Score And Save Your Life

❑ Male ❑ Female

Name Today's Date

Only your doctor can determine if you are at risk for Deep Vein Thrombosis (DVT), a blood clot that forms in one of the deep veins of your legs. A review of your personal history and current health may determine if you are at risk for developing this condition. Take a moment to complete this form for yourself (or complete it for a loved one). Then be sure to talk with your doctor about your risk for DVT and what you can do to help protect against it. Your doctor may want to keep a copy in your file for future reference.

Directions:

1. Check all statements that apply to you.
2. Enter the number of points for each of your checked statements in the space at right.
3. Add up all points to reach your total DVT Risk Score.

Then, share your completed form with your doctor.

Add 1 point for each of the following statements that apply now or within the past month:

- ❑ Age 41– 60 years ____
- ❑ Minor surgery (less than 45 minutes) is planned ____
- ❑ Past major surgery (more than 45 minutes) within the last month ____
- ❑ Visible varicose veins ____
- ❑ A history of Inflammatory Bowel Disease (IBD) (for example, Crohn's disease or ulcerative colitis) ____
- ❑ Swollen legs (current) ____
- ❑ Overweight or obese (Body Mass Index above 25) ____
- ❑ Heart attack ____
- ❑ Congestive heart failure ____
- ❑ Serious infection (for example, pneumonia) ____
- ❑ Lung disease (for example, emphysema or COPD) ____
- ❑ On bed rest or restricted mobility, including a removable leg brace for less than 72 hours ____
- ❑ Other risk factors (1 point each)*** ____

****Additional risk factors not tested in the validation studies but shown in the literature to be associated with thrombosis include BMI above 40, smoking, diabetes requiring insulin, chemotherapy, blood transfusions, and length of surgery over 2 hours.*

For women only: Add 1 point for each of the following statements that apply:

- ❑ Current use of birth control or Hormone Replacement Therapy (HRT) ____
- ❑ Pregnant or had a baby within the last month ____
- ❑ History of unexplained stillborn infant, recurrent spontaneous abortion (more than 3), premature birth with toxemia or growth restricted infant. ____

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February 2013

Add 2 points for each of the following statements that apply:

- ❑ Age 61–74 years ____
- ❑ Current or past malignancies (excluding skin cancer, but not melanoma) ____
- ❑ Planned major surgery lasting longer than 45 minutes (including laparoscopic and arthroscopic) ____
- ❑ Non-removable plaster cast or mold that has kept you from moving your leg within the last month ____
- ❑ Tube in blood vessel in neck or chest that delivers blood or medicine directly to heart within the last month (also called central venous access, PICC line, or port) ____
- ❑ Confined to a bed for 72 hours or more ____

Add 3 points for each of the following statements that apply:

- ❑ Age 75 or over ____
- ❑ History of blood clots, either Deep Vein Thrombosis (DVT) or Pulmonary Embolism (PE) ____
- ❑ Family history of blood clots (thrombosis) ____
- ❑ Personal or family history of positive blood test indicating an increased risk of blood clotting ____

Add 5 points for each of the following statements that apply now or within the past month:

- ❑ Elective hip or knee joint replacement surgery ____
- ❑ Broken hip, pelvis or leg ____
- ❑ Serious trauma (for example, multiple broken bones due to a fall or car accident) ____
- ❑ Spinal cord injury resulting in paralysis ____
- ❑ Experienced a stroke ____

Add up all your points to get your total Caprini DVT Risk Score ____

What does your Caprini DVT Risk Score mean?

- Risk scores may indicate your odds of developing a DVT during major surgery or while being hospitalized for a serious illness.
- Airplane passengers who fly more than five hours may also be at risk for DVT.
- Studies have shown if you have 0-2 risk factors, your DVT risk is small. This risk increases with the presence of more risk factors.
- Please share this information with your doctor who can determine your DVT risk by evaluating all of these factors.

Fig. 1 The Caprini risk assessment model (version 2013) (source: Dr. Joseph Caprini and the Illinois Medical Society).

0.05. The statistical analyses were conducted using IBM SPSS software version 25 (IBM, Armonk, New York, United States). The results were also analyzed using GraphPad Prism 9.0 (La Jolla, California, United States).

Results

In this study, a total of 3,807 patients were included, comprising 2,580 females and 1,227 males, with a mean age of

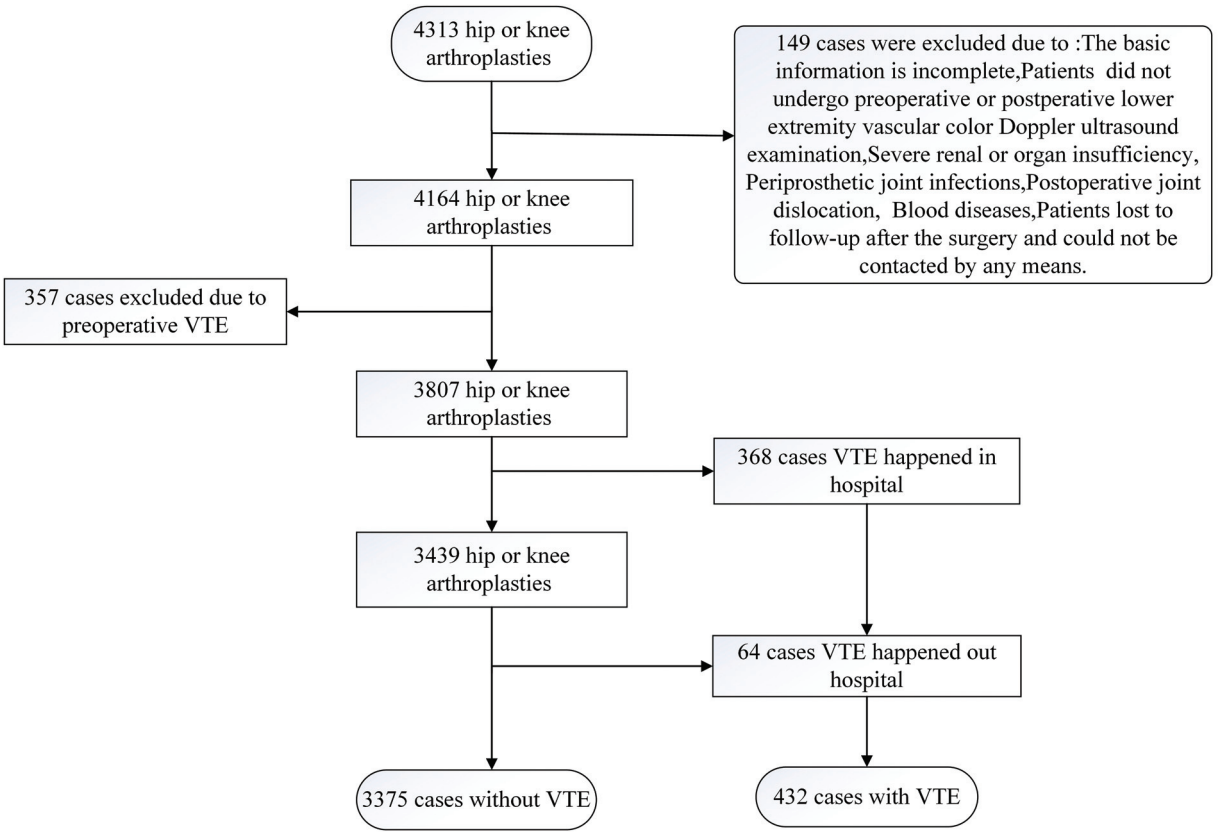

Fig. 2 Selection of the study cohort. VTE, venous thromboembolism.

64.79 ± 12.17 years. Of these patients, 432 (11.35%) were diagnosed with VTE, while 3,375 were diagnosed as non-VTE. Among the patients, 32 (0.84%) had symptomatic VTE, while 400 (10.51%) had asymptomatic VTE. Additionally, 368 (9.67%) patients were found to have VTE during their hospital stay, with one patient being diagnosed with PE by CTPA (computed tomography pulmonary angiography). All patients were followed up within 3 months after discharge. Among them, 1,787 patients returned to the hospital for lower extremity vascular ultrasound examinations. The remaining patients were contacted via telephone for their follow-up. Patients who were unable to come back for examinations were asked about any thrombosis-related symptoms and were advised to seek ultrasound examinations at their local hospitals. During the follow-up period, 64 (1.68%) patients with newly discovered cases of DVT were identified. The locations of 432 VTE cases are summarized in ►**Table 1**.

Demographic Characteristics

The age of the VTE group was significantly higher (70.16 ± 8.85 years) compared with the non-DVT group (64.11 ± 12.37 years) ($p < 0.001$). Additionally, there was a marked difference in the percentage of females between the VTE group (83.56%) and the non-VTE group (64.70%) ($p < 0.001$). The prevalence of hypertension was also significantly higher in the VTE group (55.10%) when compared with the non-VTE group (45.21%) ($p < 0.001$). Additionally, the amount of blood loss was less in the VTE group (219.06 ± 139.53 mL) than in the non-VTE group (241.45 ± 172.02 mL) ($p < 0.001$).The D-dimer levels on the third day after surgery were statistically different between the VTE group (2.71 ± 2.08 mg/L) and the non-VTE group (2.09 ± 1.57mg/L) ($p < 0.001$). The percentage of knee

Table 1 Locations and number of VTE

Locations	Number of cases
PE	1 (0.23%)
Proximal DVT	14 (3.24%)
Femoral	4 (0.93%)
Femoral + peroneal	1 (0.23%)
Femoral + muscular	2 (0.46%)
Popliteal	3 (0.69%)
Popliteal + muscular	4 (0.93%)
Distal DVT	417 (96.53%)
Peroneal	7 (1.62%)
Peroneal + muscular	3 (0.69%)
Posterior tibial	2 (0.46%)
Posterior tibial + muscular	4 (0.93%)
Posterior tibial + peroneal + muscular	2 (0.46%)
Muscular	399(92.36%)
Total	432(100%)

Abbreviations: DVT, deep vein thrombosis; PE, pulmonary embolus; VTE, venous thromboembolism.

Table 2 Demographic characteristics of VTE group and non-VTE group

	VTE	Non-VTE	t/χ^2	*p*-Value
Age (y)	70.16 ± 8.85	64.11 ± 12.37	9.46	<0.001
BMI (kg/m^2)	25.55 ± 4.05	25.55 ± 4.16	1.906	0.057
Diabetes	66 (15.28%)	498 (14.76%)	0.083	0.774
Female	361 (83.56%)	2,119 (64.70%)	61.323	<0.001
Hypertension	243 (55.10%)	1,526 (45.21%)	2.346	<0.001
Operation time (min)	106.56 ± 35.53	105.83 ± 34.08	0.414	0.679
Blood lose (mL)	219.06 ± 139.53	241.45 ± 172.02	2.384	0.017
D-Dimer (mg/L)	2.71 ± 2.08	2.09 ± 1.57	6.838	<0.001
Knee joint arthroplasty	276 (63.89%)	1,531 (45.36%)	52.712	<0.001

Abbreviations: BMI, body mass index; VTE, venous thromboembolism.

Table 3 Multivariate logistic regression analysis of the various risk factors

Risk factors	B	SE	Wals	OR	Exp(B) 95% CI	*p*-Value
Age (y)	0.622	0.086	52.332	1.862	(1.574–2.204)	<0.001
Female	0.809	0.148	29.910	2.246	(1.680–3.001)	<0.001
Hypertension	0.086	0.118	0.535	1.090	(0.865–1.373)	0.465
D-Dimer(mg/L)	0.171	0.029	35.775	1.186	(1.121–1.254)	<0.001
Knee joint arthroplasty	0.564	0.119	22.627	1.757	(1.393–2.217)	<0.001

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

arthroplasty in the VTE group (63.89%) was higher than that in the non-VTE group (45.36%) ($p < 0.001$). However, there were no significant differences in BMI, diabetes, or operation time between the VTE and non-VTE groups ($p > 0.05$). The detailed results are shown in ►**Table 2**. Multivariate regression identified that age, female, D-dimer, and knee arthroplasty were independent risk factors for VTE following TJA, and the corresponding odds ratios were 1.862 (1.574–2.204), 2.246 (1.680–3.001), 1.186 (1.121–1.254), and 1.757 (1.393–2.217) ($p < 0.05$), as is shown in ►**Table 3**.

VTE and Caprini RAM

Patients were evaluated using the Caprini RAM, which includes various risk factors for VTE.[20] The relevant risk factors and their corresponding scores are listed in ►**Table 4**. Statistical analysis revealed significant differences between the VTE and non-VTE groups in terms of age groups 41–60 years, 61–74 years, and ≥75 years, BMI >25, visible varicose veins, swollen legs, smoking, and history of blood clots, and broken hip ($p < 0.05$). However, there were no statistically significant differences in terms of BMI >40, history of inflammatory bowel disease, congestive heart failure, lung disease, diabetes requiring insulin, use of hormone arthroplasty therapy, blood transfusion, duration of bed rest, or malignancies ($p > 0.05$). The mean Caprini score of the VTE group (10.10 ± 2.23) was higher than that of the non-VTE group (9.35 ± 2.14) ($p < 0.001$). The detailed results are shown in ►**Table 4**.

The distribution of the number of patients in different scores and the incidence of VTE in different scores are shown in ►**Fig. 3**. Among the 74 patients with a score of 6, there were no reported cases of VTE. However, for the 380 patients with a score of 7, the incidence of VTE was 5%. Among the 888 patients with a score of 8, the incidence of VTE was 7.43%, while for the 1,250 patients with a score of 9, the incidence of VTE was 11.44%. Among the 531 patients with a score of 10, the incidence of VTE was 17.14%. For the 142 patients with a score of 11, the incidence of VTE was 18.31%. Among the 62 patients with a score of 12, the incidence of VTE was 12.9%. For the 119 patients with a score of 13, the incidence of VTE was 16.81%. Among the 189 patients with a score of 14, the incidence of VTE was 17.46%. For the 113 patients with a score of 15, the incidence of VTE was 15.04%. Among the 43 patients with a score of 16, the incidence of VTE was 15.04%. For the 15 patients with a score of 17, the incidence of VTE was 26.67%. Finally, it is worth noting that out of all the patients, only one had a score of 19 and there was no incidence of VTE in this case. The incidence of VTE increases with the increase of the score. However, it is worth noting that the number of patients with a score of 12 or higher is relatively low, and individual cases can easily disrupt the incidence of VTE. In fact, the incidence of VTE at 19 points is based on a single patient, rendering this data point unreliable for drawing conclusions about the relationship between score and VTE incidence. Therefore, we removed this outlier from our analysis and conducted a correlation analysis to better understand the relationship between VTE incidence and score. A strong correlation exists between the incidence of VTE and the Caprini score ($r = 0.775$, $p = 0.003$, ►**Fig. 4**).

Table 4 Caprini risk factors between VTE group and non-VTE group

Relative risk factors	Risk score	VTE (*n*, %)	Non-VTE (*n*, %)	χ^2	*p*-Value
Age 41–60 y	1	49 (11.34)	900 (26.667)	48.057	<0.001
Age 61–74 y	2	244 (56.48)	1674 (49.60)	7.255	0.007
Age ≥ 75 y	3	138 (31.94)	629 (18.64)	42.156	<0.001
BMI > 25	1	233 (53.93)	1675 (49.63)	2.840	0.092
BMI > 40	2	1 (0.23)	6 (0.18)	0.060	0.806
Visible varicose veins	1	16 (3.70)	58 (1.72)	7.919	0.005
History of inflammatory bowel disease	1	0 (0)	1 (0.03)	0.128	0.720
Swollen legs (current)	1	24 (5.56)	99 (2.93)	8.432	0.004
Congestive heart failure	1	3 (0.69)	24 (0.71)	0.002	0.969
Lung disease (e.g., emphysema or COPD)	1	2 (0.46)	25 (0.74)	0.420	0.517
Smoking	1	19 (4.40)	263 (7.79)	6.434	0.011
Diabetes requiring insulin	1	11 (2.55)	88 (2.61)	0.006	0.940
For women current use of hormone arthroplasty therapy (HRT)	1	0 (0)	1 (0.03)	0.128	0.720
Blood transfusion	1	47 (10.88)	358 (10.61)	0.030	0.863
On bed for less than 3 days	1	397 (91.90)	3,125 (92.60)	0.267	0.606
On bed for 3 or more days	2	35 (8.10)	250 (7.41)	0.267	0.606
Current or past malignancies	2	20 (4.630)	124 (3.674)	0.961	0.327
History of blood clots	3	5 (1.157)	9 (0.267)	8.293	0.004
Broken hip	5	75 (17.36)	409 (12.12)	9.485	0.002
Caprini Score	–	10.10 ± 2.23	9.35 ± 2.14	$t = 6.845$	<0.001

Abbreviations: BMI, body mass index; COPD, chronic obstructive pulmonary disease; VTE, venous thromboembolism.

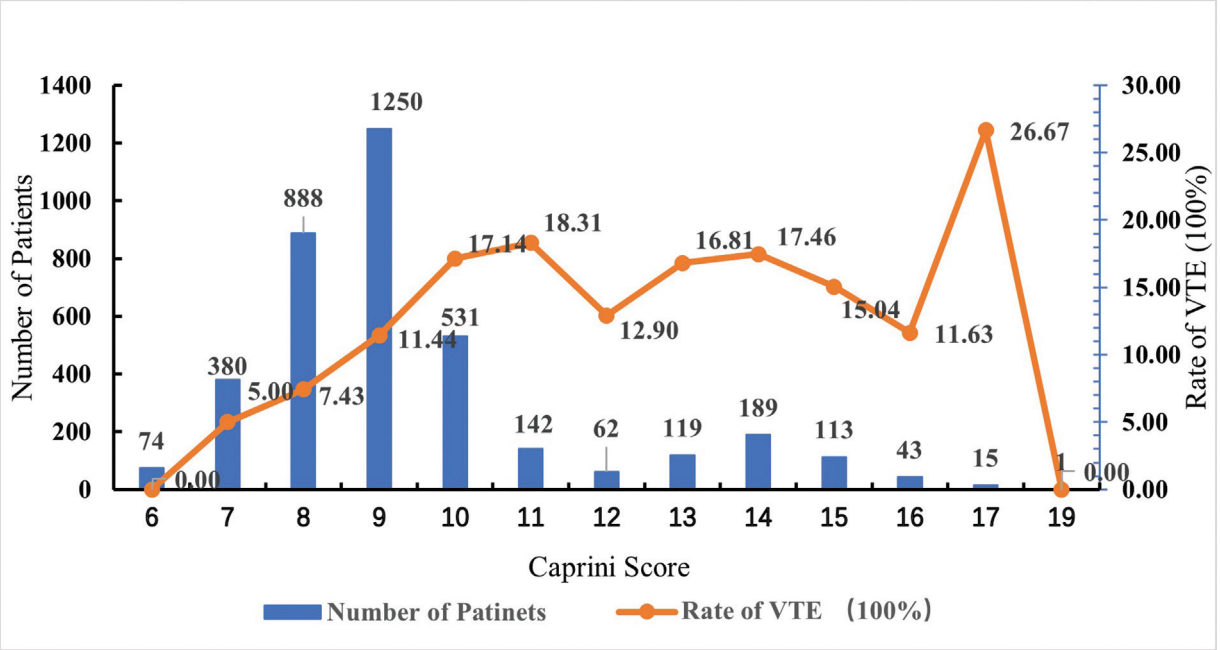

Fig. 3 The number of patients and the incidence of VTE at different Caprini scores. VTE, venous thromboembolism.

The analysis of the ROC curve for the Caprini score and VTE incidence resulted in an AUC of 0.619 (refer to ►**Fig. 5**). The optimum cutoff value of 8.5 points is presented in ►**Table 5**. The findings of this study suggest that patients with a score of 9 or higher may be at a greater risk of developing VTE after arthroplasty. Furthermore, upon comparing the rate of VTE among different scores with the overall rate, it was discovered that the incidence of VTE at a score of 9

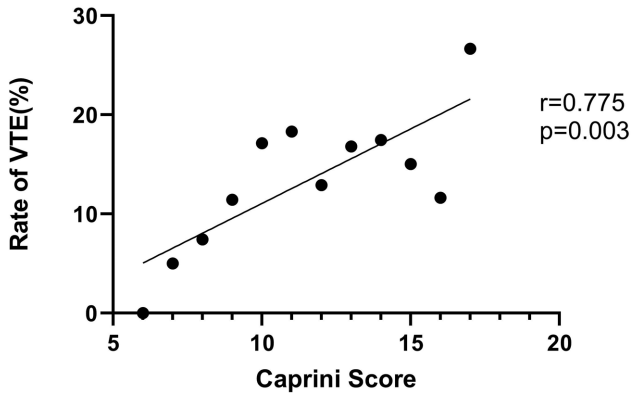

Fig. 4 The correlation between the incidence of VTE and the Caprini score. The incidence of VTE at 19 points was based on a single patient, and thus these data were disturbing and removed. VTE, venous thromboembolism.

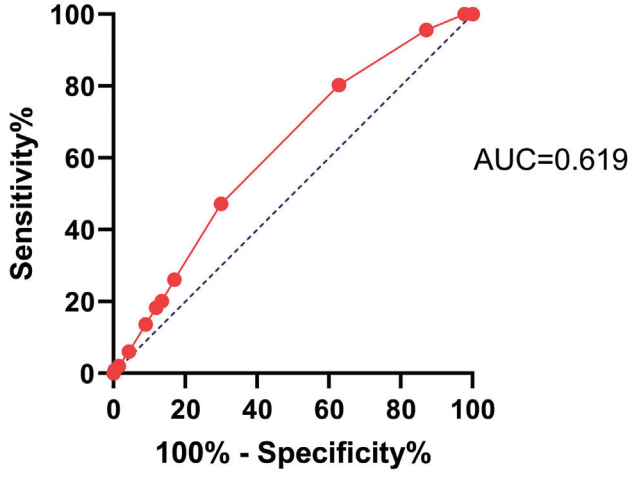

Fig. 5 The ROC (receiver operating characteristic) curve for Caprini score. AUC (area under the curve) of 0.619.

Table 5 The effectiveness of the Caprini score when selecting different cutoff values

Caprini Score	Sensitivity	1 - Specificity	Youden Index
5	1	1	0
6.5	1	0.978	0.022
7.5	0.956	0.871	0.085
8.5	0.803	0.628	0.175
9.5	0.472	0.3	0.172
10.5	0.262	0.169	0.093
11.5	0.201	0.135	0.066
12.5	0.183	0.119	0.064
13.5	0.137	0.089	0.048
14.5	0.06	0.043	0.017
15.5	0.021	0.015	0.006
16.5	0.009	0.004	0.005
18	0	0	0
20	0	0	0

Note: The Caprini Score 8.5 has a maximal Youden Index, and the optimal cutoff value is also 8.5.

Table 6 The comparison of different scores with overall rate of VTE

Total	Caprini ≥ 7	Caprini ≥ 8	Caprini ≥ 9
432 (11.35%)	432 (11.57%)	413 (12.32%)	347 (14.08%)
χ^2	0.094	1.611	10.248
p	0.759	0.204	0.001

Abbreviation: VTE, venous thromboembolism.

or higher was higher than the mean rate of VTE in all patients (refer to ►**Table 6**).

To account for the limited sample size in certain score groups, we have stratified the scoring system into three categories: ≤8 points, 9–11 points, and ≥12 points. The corresponding population sizes were 1,342, 1,923, and 542 individuals, respectively, with VTE incidence rates of 6.33, 13.52, and 16.05%. The group with a score of ≤8 had a significantly lower incidence rate of VTE compared with the groups with scores of 9–11 and ≥12 points ($p < 0.001$), while no significant statistical difference was observed between the 9–11 points and the ≥12 points groups in terms of VTE incidence rates ($p > 0.05$). The comparison results are shown in ►**Fig. 6**.

The probability of developing DVT after knee arthroplasty surgery is higher than after hip arthroplasty surgery due to the greater impact on lower limb blood circulation. To determine whether a Caprini score of 9 is the cutoff point for VTE occurrence in both types of surgeries, we analyzed the number of patients and VTE occurrence rates for knee and hip arthroplasty surgeries separately. It can be seen that regardless of the overall patients, knee and hip arthroplasty surgeries, the VTE occurrence rates with Caprini score ≥9 were 14.08, 17.41, and 10.47%, respectively, all of which were higher than the VTE occurrence rates of 6.33, 10.13, and 3.91% for Caprini score <9 ($p < 0.001$), as shown in ►**Table 7**.

Out of 432 patients with VTE, 32 had symptomatic VTE. When comparing the Caprini scores between the symptomatic and asymptomatic VTE groups, there was no significant difference found ($p > 0.05$). The average Caprini score for the symptomatic VTE group was 10.13 ± 2.21, while the asymptomatic VTE group had an average score of 10.10 ± 2.23. However, it was observed that both groups had higher scores than the non-VTE group, which had an average score of 9.35 ± 2.14 ($p < 0.05$, ►**Fig. 7**).

Among the 432 VTE patients, 368 developed VTE during hospitalization with a Caprini score of 10.08 ± 2.22, while 64 developed VTE after discharge with a Caprini score of 10.22 ± 2.31. There was no statistically significant difference between the two groups ($p > 0.05$); however, both groups had higher scores than the no-VTE group, which had a score of 9.35 ± 2.14 ($p < 0.05$, ►**Fig. 8**).

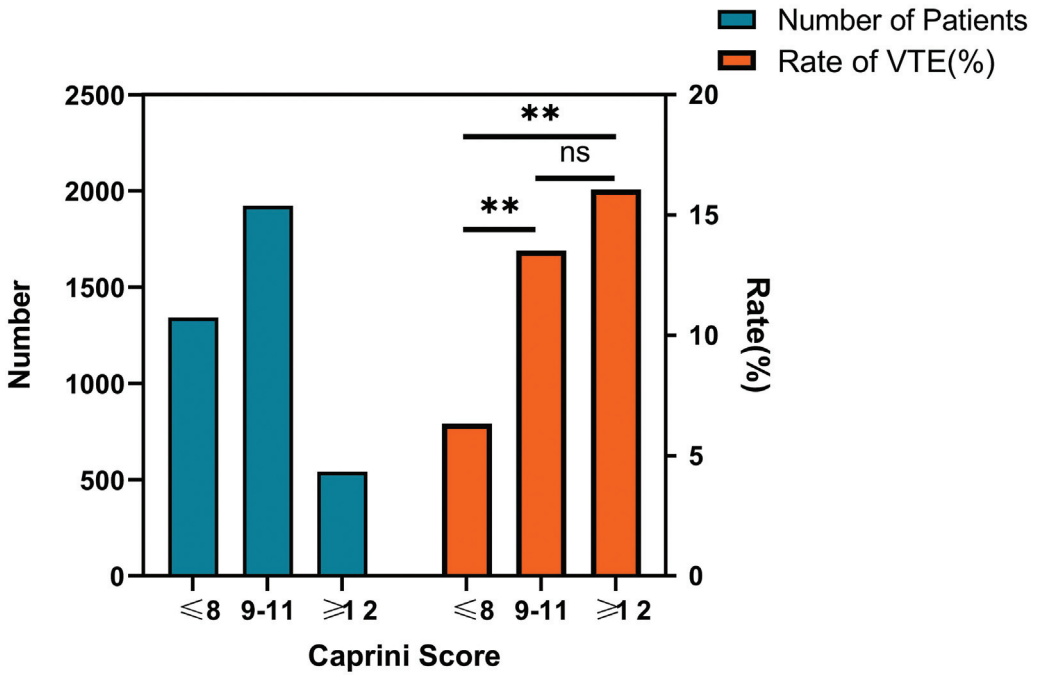

Fig. 6 The number of patients and the incidence of VTE in different Caprini score ranges. VTE, venous thromboembolism. ns = $p > 0.05$. $^{**}p < 0.001$.

Table 7 VTE rates of knee and hip arthroplasty surgeries were analyzed for Caprini score <9 and ≥9

	Total VTE rate	Knee VTE rate	Hip VTE rate
Caprini < 9	85 (6.33%)	53 (10.13%)	32 (3.91%)
Caprini ≥ 9	347 (14.08%)	223 (17.41%)	124 (10.47%)
χ^2	51.847	15.165	29.060
p	<0.001	<0.001	<0.001

Abbreviation: VTE, venous thromboembolism.

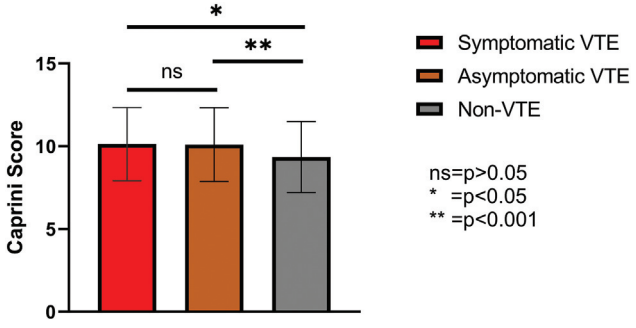

Fig. 7 The comparison of Caprini scores between symptomatic VTE, asymptomatic VTE, and non-VTE cases. VTE, venous thromboembolism. ns = $p > 0.05$, $^{*}p < 0.05$, $^{**}p < 0.001$.

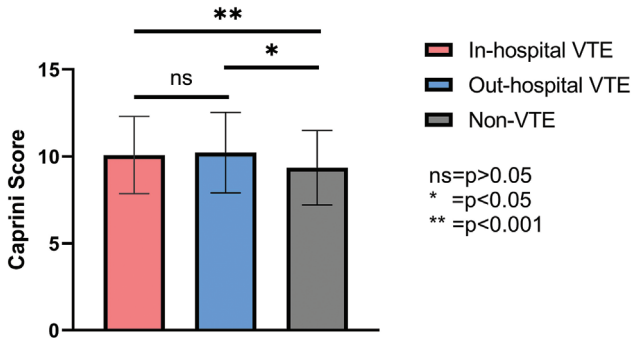

Fig. 8 The comparison of Caprini scores between in-hospital VTE, out-hospital VTE, and non-VTE cases. VTE, venous thromboembolism. ns = $p > 0.05$, $^{*}p < 0.05$, $^{**}p < 0.001$.

Discussion

Reducing the occurrence of VTE after TJA has always been a major concern for physicians. Currently, we primarily employ a multimodal approach for anticoagulation measures. Physical prophylaxis involves the use of pneumatic compression devices and elastic stockings, as well as guidance from a specialized rehabilitation team for ankle pumps and ambulation exercises.[27] Pharmacological prophylaxis involved the administration of one of several anticoagulant medications, such as low-molecular-weight heparin, dabigatran, aspirin, and fondaparinux.[28] Despite implementing these measures, there is still a VTE occurrence rate of 11.35% among TJA patients, with 0.84% experiencing symptomatic VTE. Therefore, many researchers are seeking better methods to prevent and manage VTE in patients undergoing joint arthroplasty surgery. One effective tool for predicting the likelihood of thrombotic events and determining appropriate prophylactic measures is RAMs, such as the Caprini RAM. Our study found that the Caprini score was significantly higher in the VTE group (10.10 ± 2.23) compared with the non-VTE group (9.35 ± 2.14) ($p < 0.001$). We also observed a strong correlation between the Caprini score and

incidence of VTE ($r = 0.775$, $p = 0.003$), with higher scores indicating a greater likelihood of developing VTE. This further underscores the role of the Caprini RAM in TJA, highlighting its effectiveness in providing a reliable risk assessment for VTE occurrence. These findings align with results from studies conducted on other surgical procedures,[25,29] indicating a certain level of consistency in the predictive capabilities of the Caprini RAM across various surgical contexts.

To effectively capture the impact of the Caprini RAM in the context of post-arthroplasty patients, who generally exhibit higher Caprini scores, certain scholars have devised elevated risk thresholds for VTE prediction based on their research findings. They have concluded that a score of 8 to 10 or higher has a greater predictive value for VTE in various patient populations.[19,21] It should be noted that these studies only focused on symptomatic VTE and did not take into account asymptomatic VTE. Therefore, it is not reasonable to assess the accuracy of the Caprini score based solely on symptomatic thrombus.[30] In this study, the Caprini score did not differ significantly between the symptomatic and asymptomatic VTE groups ($p > 0.05$). However, both VTE groups had significantly higher Caprini scores compared with the non-VTE group ($p < 0.05$). After conducting a more comprehensive and accurate VTE screening and comparing it with the Caprini score, we concluded that a score of $\geq$9 is a high-risk factor for all post joint arthroplasty thrombotic events.

There are many scoring options, but after our analysis of 3,807 arthroplasty patients, there are so many items, including age, BMI >25, visible varicose veins, history of blood clots, broken hip, and swollen legs in joint arthroplasty, that play a role in influencing the occurrence of VTE. In addition to some of the items in the score, some indicators such as female, hypertension, and D-dimer differed between the VTE and non-VTE groups and had an impact on the occurrence of thrombosis. This finding is consistent with the analysis conducted by Zeng et al, which suggests that patients who have cardiovascular disease, a prior history of VTE, neurological disease, or high anesthesia American Society of Anesthesiologists (ASA) scores are at a greater risk of developing VTE following arthroplasty.[31] For some other Caprini scoring items such as BMI >40, history of inflammatory bowel disease, congestive heart failure, lung disease, diabetes requiring insulin, hormone arthroplasty therapy, malignancies, although others have reported some variability in the occurrence of VTE in joint arthroplasty, the number of patients in these categories was small in our study, so the variability was not exposed.

The VTE and non-VTE groups did not show any significant differences in blood transfusion or duration of bed rest, as routine joint arthroplasty surgery typically does not require blood transfusion or bed rest exceeding 3 days. However, patients undergoing complex surgery for developmental dysplasia of the hip may require blood transfusion and extended bed rest. It is worth noting that these patients are typically younger and have lower Caprini score. Additionally, the VTE group consisted of a larger proportion of elderly patients, whereas the non-VTE group had younger patients who underwent more dysplasia or revision surgeries. The elderly patients in the VTE group could increase the likelihood of requiring blood transfusions due to their weaker physical condition.[32] Therefore, the transfusion rates were similar for both groups. In our study, the smoking rate was found to be lower in the VTE group. However, we cannot consider smoking as a protective factor since it is a well-known risk factor for thrombosis.[33] The lower smoking rate in the VTE group can be attributed to a higher proportion of females, as multiple studies have confirmed that female patients have a higher incidence of VTE after joint arthroplasty surgery compared with male patients.[34,35] Due to the lower smoking rate among female patients, there is a gender-related interference in the smoking rate, which manifests as a lower smoking rate in the VTE group.

Although the Caprini score is widely used in the weeks to months after surgery, the exact timing of its application is not uniformly defined. Several studies have applied the Caprini score up to 3 months postoperatively to predict the risk of DVT and PE.[36] While some studies do track the incidence of thrombosis within 90 days, they do not actively monitor patients utilizing Caprini scores and ultrasounds, but simply investigate their re-visits within that time frame. As a result, their findings lack convincing evidence.[30] However, the Caprini scores of patients who developed VTE after being discharged were found to be higher than those of the no-VTE group, suggesting that the Caprini score can predict the risk of VTE in patients over a specific period of time. Even though patients with high scores did not experience VTE during hospitalization, they still have a higher risk of VTE in the 3 months after discharge.

As the incidence of thrombosis after joint arthroplasty surgery has gradually decreased, some researchers have begun to utilize shorter term postoperative anticoagulation or aspirin-only anticoagulation protocols.[21,37] This study suggests that patients with higher Caprini scores should receive more intensive anticoagulation therapy to prevent thrombosis. Our study adds to the increasing evidence supporting the use of the Caprini score as a risk assessment tool in joint arthroplasty surgery. Additionally, our findings shed light on the potential advantages of customizing anticoagulation regimens for patients at high risk. Moving forward, it would be beneficial for future research to concentrate on creating more precise and personalized risk stratification tools that take into account a broader range of patient factors. This would ultimately lead to improved efficacy and safety of thromboprophylaxis in this population.

The mandatory use of the Caprini score for thrombotic risk assessment can increase physician awareness of preventing and treating thrombosis, leading to a reduction in the incidence of thrombotic events.[38] In addition, patients with higher Caprini scores are at an increased risk of experiencing postoperative complications such as wound dehiscence, infection, seroma, hematoma, and necrosis.[39] This indicates that the Caprini score can effectively reflect the overall functional status of the body, making it a valuable predictor not only for the risk of thrombosis but also for other complications. It should be noted that the Caprini score is

intended as a risk assessment tool rather than a diagnostic criterion, and its diagnostic performance is relatively low, with an area under the ROC curve of just 0.613. Nevertheless, a higher Caprini score still suggests a greater likelihood of thrombotic complications.

Our study has several advantages. First, it features the largest sample size of patients who underwent lower limb vascular color Doppler ultrasound examination after joint arthroplasty surgery. Second, our study aims to evaluate the correlation between postoperative VTE and the corresponding Caprini score. To achieve this, we performed preoperative lower limb vascular color Doppler ultrasound examinations on all patients to exclude preoperative DVT. This approach will result in more accurate and reliable results. Third, the follow-up was conducted on a cohort of 3,807 patients, and a cohort of 1,787 patients, and dedicated personnel conducted assessments and lower extremity vascular color Doppler examinations at our hospital within 2 months after surgery. This follow-up procedure and the resulting data are of superior reliability compared with those of other studies. Fourth, we are utilizing content from a specialized thrombosis database, rather than relying solely on the medical records system for retrospective analysis. This ensures higher accuracy and reliability of the data and results.

In addition, our study has some limitations that need to be acknowledged. First, the diagnosis of DVT is usually done through vascular color Doppler ultrasound, which is popular but not as accurate as the gold standard, lower limb venography. However, venography is invasive, which is why color Doppler ultrasound is still the preferred method for diagnosing DVT. Second, our study is limited by the small sample size in certain items of the Caprini RAM, such as BMI >40, history of inflammatory bowel disease, and congestive heart failure, which may have prevented us from identifying certain significant relationships among variables. Third, we only examined patients who underwent joint arthroplasty surgery at a single institution, which may limit the external validity of our results. Fourth, the majority of VTE events were isolated muscular vein thrombosis. Although some scholars may argue that muscular vein thrombosis has limited clinical significance, it can actually serve as an indicator of the thrombotic state in the body and carries a risk of further thrombotic progression. Finally, we did not investigate the impact of different anticoagulation regimens on patient outcomes, which is an important area for future research. Although there were continuous changes and adjustments in anticoagulant drugs and anticoagulation regimens between 2015 and 2021, the anticoagulation regimens used for patients during the same period were generally consistent.

Conclusion

The Caprini RAM exhibits a robust correlation with the incidence of VTE, with a greater score reflecting a heightened risk of developing VTE. The prevalence of VTE is particularly high following joint arthroplasty surgery, and patients with a Caprini score of ≥ 9 are at an even greater risk of developing VTE. The Caprini RAM serves as a valuable tool for categorizing VTE risk following joint arthroplasty and can provide a pre-emptive alert for VTE onset.

What is known about this topic?

- The Caprini risk assessment model (RAM) is commonly used for evaluating venous thromboembolism (VTE) risk in patients who undergo arthroplasty.
- Arthroplasty patients may be classified as high risk for VTE based on high Caprini RAM scores.
- The occurrence of VTE after arthroplasty is a significant concern and has been subject to debate in the literature.
- The Caprini RAM includes several risk factors for VTE, but not all of these may be applicable to arthroplasty surgery.

What does this paper add?

- This retrospective study adds evidence to support the significant correlation between Caprini RAM scores and the occurrence of VTE in patients who undergo arthroplasty.
- The study provides data on the incidence of symptomatic and asymptomatic VTE, as well as VTE events during hospitalization and postdischarge follow-up.
- The study contributes to the existing knowledge on risk factors for VTE after arthroplasty, including age, blood loss, D-dimer levels, BMI >25, visible varicose veins, swollen legs, smoking, history of blood clots, broken hip, percent of female, hypertension, and knee joint arthroplasty.
- The article suggests that a score ≥ 9 is a high-risk threshold for postoperative VTE and recommends appropriate prophylaxis.

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Conflict of Interest
None declared.

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