Article

Impact of Combining Ultrasound Parameter and the Caprini Score on Predicting Lower Extremity Deep Venous Thrombosis After Orthopedic Surgery

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AIMS: This study combined a new ultrasound venous filling degree (VFD) parameter with the Caprini score to assess the clinical value of the Caprini score in predicting deep venous thrombosis (DVT) of the lower extremities.
METHODS: This retrospective study included 150 inpatients undergoing orthopedic lower extremity surgery at the First Affiliated Hospital of the Air Force Medical University between June 2023 and June 2024. They included 41 (27.3%) cases of knee arthroplasty, 32 (21.3%) hip arthroplasty, 30 (20%) knee arthroscopy, 28 (18.7%) lower limb fractures, 12 (8%) bone tumor, and 7 (4.7%) cases of other surgery types. The data collected involved preoperative vein diameter, flow velocity, blood flow, venous lumen cross-sectional perimeter (C), lumen cross-sectional area (A), C^2/A ratio (VFD) of the common femoral vein (CFV), femoral vein (FV), and popliteal vein (POV). The postoperative sonographic parameters and clinical data were compared between the DVT and non-DVT groups. Receiver operating characteristic (ROC) curve of parameters was evaluated as predictive values for DVT. Additionally, the C^2/A ratio was combined with the Caprini score to assess their combined impact on DVT prediction.
RESULTS: There were significant differences in ultrasound parameters of CFV inner diameter, CFV blood flow, CFV-C, CFV-A, CFV-C^2/A, FV blood flow, FV-C, FV-C^2/A, POV blood flow, POV-C, POV-A, and POV-C^2/A between the DVT group (24.7%, 37/150) and the non-DVT group (75.3%, 113/150) (all $p < 0\ .05$). Area under curve (AUC) for the C^2/A (CFV, FV, and POV) were 0.939 (95% confidence interval (CI): 0.888–0.972, $p < 0.001$), 0.937 (95% CI: 0.886–0.970, $p < 0.001$), and 0.917 (95% CI: 0.861–0.956, $p < 0.001$), respectively. When the Caprini score >2, an AUC for predicting DVT was 0.844 (95% CI: 0.776–0.899, $p < 0.001$). The AUC of the Caprini score >2 combined with C^2/A (CFV, FV, and POV) were 0.953 (95% CI: 0.905–0.981, $p < 0.001$), 0.965 (95% CI: 0.922–0.988, $p < 0.001$), and 0.948 (95% CI: 0.900–0.978, $p < 0.001$), respectively.
CONCLUSIONS: The ultrasound parameter of VFD-C^2/A shows a high predictive value for DVT in patients undergoing orthopedic surgery. Combined with the Caprini score, the predictive value of DVT may be further enhanced compared to using the Caprini score alone.

Keywords: ultrasonography; Caprini score; deep venous thrombosis of lower extremities; prevention

Introduction

Deep venous thrombosis (DVT) of the lower extremities is a common condition affecting both medical and surgical patients, posing a significant burden on global healthcare costs, and leading to substantial morbidity and mortality [1–4]. In China, the prevalence and diagnosis rate of DVT has been increasing annually [5,6]. According to the consensus of the Asia-Pacific Thrombosis Advisory Committee on preventing venous thromboembolism after major orthopedic surgery and relevant national guidelines, orthopedic procedures, especially hip and knee arthroplasty, are a primary cause of DVT, with incidence rates reaching up to 61.0% [7]. Venous thromboembolism (VTE), including DVT and pulmonary embolism (PE), is a leading cause of perioperative death in orthopedic surgery and a crucial contributor to preventable death in hospitals [8], posing a severe threat to the patient's health. Early prevention of DVT is of great significance as it is the main cause of PE.

The 2010 edition of the Chinese Guideline for the Prevention of Venous Thromboembolism in Orthopedic Surgery [9], recommends the Caprini score as a risk assessment tool for VTE in orthopedic patients [10–13]. While the Caprini score has been proven effective in predicting VTE incidence in patients with stroke, tumor surgery, and plastic surgery, and its limitations in risk classification, especially in high-risk populations and in the formulation of preventive measures may affect the accuracy of VTE prediction and outcome in orthopedic patients [14–21]. Ultrasound, with an accuracy of 93.2%, is the gold standard for DVT

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diagnosis [22]. However, study on the early prediction of DVT in asymptomatic patients using ultrasonographic parameters are limited [23]. Previous studies have investigated venous diameter and blood flow velocity in lower extremities to evaluate proximal vein conditions in DVT [24,25]. However, these factors are easily affected by respiration [26], body position [27], lower extremity edema [28], hydration status [29], and mass compression [30], which can impact the stability and repeatability of ultrasonic data, thus reducing its predictive accuracy for DVT.

To improve the accuracy of ultrasound in predicting DVT, this study investigated the application of a sonographic parameter known as venous filling degree (VFD). VFD is defined as venous cross-sectional perimeter^2 divided by the cross-sectional area (C^2/A), providing a stable constant that may address the variabilities described earlier. Furthermore, the study explored the predictive value of VFD for DVT in orthopedic patients both independently and in combination with the Caprini score. The findings are anticipated to enhance the predictive accuracy of the Caprini score and provide new insights for the early clinical prevention of DVT.

Materials and Methods

Recruitment of Study Subjects

This retrospective study recruited 150 patients undergoing orthopedic lower extremity surgery between June 2023 and June 2024. Based on DVT occurrence after surgical procedure, patients were divided into the thrombosis (DVT group) and non-thrombosis (non-DVT group) groups. The DVT group included 37 cases and the non-DVT group consisted of 113 patients. The study design followed the ethical guidelines of the Declaration of Helsinki and was approved by the Ethics Committee of the First Affiliated Hospital of the Air Force Medical University (KY20232031-F-1). Furthermore, informed consent was obtained from all participants.

Study subjects were recruited using the predetermined inclusion criteria as follows: (1) patients aged 18–80 years; (2) those undergoing orthopedic lower extremity surgery, including knee arthroplasty, hip arthroplasty, knee arthroscopy, lower limb fracture surgery, or bone tumor surgery; (3) patients with complete clinical and ultrasonic data; (4) patients with complete medical records; and (5) those without preoperative DVT, confirmed by lower extremity color Doppler ultrasonography. However, exclusion criteria included (1) patients with a history of chronic DVT; (2) patients with coagulation disorders like hypercoagulability; (3) those with heart failure, liver or kidney failure, or venous hypertension of the lower extremities due to pelvic or abdominal tumors; and (4) pregnant or lactating women.

Ultrasonic Parameters

The common femoral vein (CFV), femoral vein (FV), and popliteal vein (POV) of both lower limbs were scanned using a color Doppler ultrasound. Furthermore, bilateral CFV, FV, POV diameters, blood flow velocity, blood flow, venous cross-sectional perimeter (C), venous cross-sectional area (A), and the ratio of C^2/A were measured and recorded. The VFD was defined as the venous cross-sectional perimeter divided by the cross-sectional area (C^2/A).

To reduce the measurement error, the following procedures were applied: (1) A higher resolution vascular ultrasound probe (3232661, Hitachi Aloka Medical Co., Ltd., Tokyo, Japan) was employed to improve image clarity. (2) Before measurement, the physician calibrated and adjusted the instrument, increasing the two-dimensional gain and scanning depth as required for obese patients. (3) Images were enlarged during measurement. (4) Ultrasound data were measured three times and averaged. (5) Patients were positioned supine with the lower limbs placed in the standard external rotation and abduction position as much as possible. (6) Measurement points were fixed at the middle of CFV near the saphenofemoral junction, 1–2 cm below the origin of FV and the middle of POV. (7) All procedures were performed by the same sonographer, who had more than 5 years of vascular ultrasound experience. (8) Probe pressure was applied to ensure adequate vein visualization without causing wall deformation.

All studies were conducted within 24 hours before the operation. The ultrasound parameters for CFV, FV, and POV were calculated as the average values for the affected leg(s) before surgery.

Clinical Data

Clinical data were collected and analyzed, including age, gender, body mass index (BMI), complications (hypertension, diabetes, coronary heart disease), preoperative laboratory data (D-dimer, platelet count, C-reactive protein, blood type), preoperative Caprini score, type of operation, operation time, tourniquet use time, and bedrest time.

Caprini score was used to assess the risk of postoperative VTE in surgical patients, classifying the risk into four levels: 1, 2, 3 and 5. The total score was calculated by summing the score assigned to each factor. A higher score suggested a greater risk of VTE. The one-point factors included age, BMI, ectopic pregnancy, postpartum status, varicose veins, and other similar conditions. The two-point factors included major surgery, age between 61–74 years, and deep vein catheterization status. The three-point factors involved age $\geq$75 years, a history of blood clots, and a family history of blood thrombosis. The five-point factors included patients with paralysis, stroke within the past month, joint replacement surgery, and multiple injuries within the past month.

Furthermore, risk levels were categorized as follows; The Caprini score of 0–2 indicated a lower risk of postoperative VTE, a score of 3–4 suggested moderate risk of VTE, and a score of $\geq$5 indicated a higher risk of VTE [31].

DVT Prevention

All patients underwent VTE prophylaxis after surgery adhering to the established guidelines [1]. DVT prevention protocols performed as follows: (1) Ealy mobilization: Patients were encouraged to ambulate as soon as possible after surgery. (2) Medication prophylaxis: Patients were administered with rivaroxaban (10 mg/d, 697465, Xinlitai Pharmaceutical Co., Ltd., Shenzhen, China). However, patients undergoing hip and knee arthroplasty or lower limb fracture surgery received anticoagulant drugs to prevent DVT during hospitalization. Rivaroxaban was given orally 6–8 hours after surgery. If there was a continued risk of bleeding at the 8-hour point after surgery, anticoagulation was delayed until 12 hours. (3) Mechanical prophylaxis: This involved the use of foot pressure pumps (20172261328, Keweihan Medical Technology Co., Ltd., Nantong, China) and compression stockings.

Post-operative DVT

The discharge records of patients were obtained from the electronic workstation of orthopedic surgeons to document postoperative DVT occurrence during hospitalization.

Statistical Analysis

Data were analyzed using MedCalc statistical software (version 15.2, MedCalc Software Ltd., Ostend, Belgium) and Statistical Package for the Social Sciences (SPSS, version 17.0, IBM Corp., Chicago, IL, USA). The One-Sample Kolmogorov-Smirnov test and P-P diagram were used for assessing normality within quantitative data. Normally distributed measurement data were expressed as mean $\pm$ standard deviation and comparison between groups was performed using an independent sample *t*-test. Moreover, nonnormally distributed data were expressed as Median (Interquartile Range), and comparison between groups was performed using the Mann-Whitney test. The χ^2 or chi-square correction test was used to compare categorical variables.

The receiver operating characteristic (ROC) curve was used to analyze the efficacy of various parameters in predicting postoperative DVT risk in orthopedic patients. The area under curve (AUC), cutoff value, sensitivity, and specificity were calculated. Each parameter was evaluated as a variable, with the occurrence of VTE at the time of discharge serving as the gold standard diagnosis. The horizontal coordinate represented 1-specificity, while the vertical coordinate represented sensitivity.

An AUC value of less than 0.5 indicated no obvious predictive value. However, an AUC value between 0.5 and 0.7 indicated low predictive efficiency, whereas an AUC between 0.7 and 0.9 suggested moderate efficiency. An AUC value above 0.9 indicated high diagnostic efficiency. The optimal cut-off value was determined using the maximum Youden index, calculated as: Youden index = sensitivity + specificity – 1. The DeLong test was used for pairwise comparison of ROC curves. Logistic regression analysis was employed to predict DVT by combining the C^2/A ratio and Caprini score. A *p*-value of $<$0.05 was considered statistically significant.

Results

Comparison of Baseline Information Between the Two Experimental Groups

This study included 69 men and 81 women, aged ranging between 18 and 80 years, with an average age of 55.1 $\pm$ 14.3 years. Among the 150 patients, 41 (27.3%) patients underwent knee arthroplasty, 32 (21.3%) patients hip arthroplasty, 30 (20%) patients knee arthroscopy, 28 (18.7%) patients lower limb fracture, 12 (8%) patients bone tumor, and 7 (4.7%) patients received other procedures.

DVT was observed in 37 (24.7%) cases, including 2 (5.4%) cases of proximal vein thrombosis (Fig. 1A), 24 (64.9%) cases of distal vein thrombosis, and 11 (29.7%) cases of mixed thrombosis. Inferior vena cava filters were placed in 18 (12%) cases, and no PE occurred among the DVT patients during hospitalization.

As summarized in Table 1, significant differences were observed between the DVT and non-DVT groups regarding age, BMI, C-reactive protein, D-dimer, Caprini score, operation type, operation time, tourniquet use time, and bedrest time (all $p < 0.05$).

Comparison of Ultrasonic Parameters Between the DVT and Non-DVT Groups

There were significant differences in CFV inner diameter, CFV blood flow, CFV-C, CFV-A, CFV-C^2/A, FV blood flow, FV-C, FV-C^2/A, POV blood flow, POV-C, POV-A and POV-C^2/A between the two groups (all $p < 0.05$). The CFV-C^2/A, FV-C^2/A, and POV-C^2/A ratios were substantially higher in the DVT group than those in the non-DVT group (Fig. 1B,C). A comparison of ultrasonic parameters between the two experimental groups is shown in Table 2 (all $p < 0.001$).

ROC Curve of Each Parameter Predicting DVT

ROC curve analysis showed that CFV diameter, CFV blood flow, CFV-C, CFV-C^2/A, FV blood flow, FV-C, FV-C^2/A, POV blood flow, POV-C, POV-A, POV-C^2/A, age, BMI, C-reactive protein, Caprini score, D-dimer, type of operation, operation time, tourniquet use time, bed time had significant predictive value for DVT in orthopedic patients. Among them, CFV-C^2/A, FV-C^2/A, and POV-C^2/A exhibited higher predictive values for DVT with ROC cutoff values $>$17.4, 17.1, and 17.0, respectively. Moreover, they showed AUC of 0.939 (95% confidence inter-

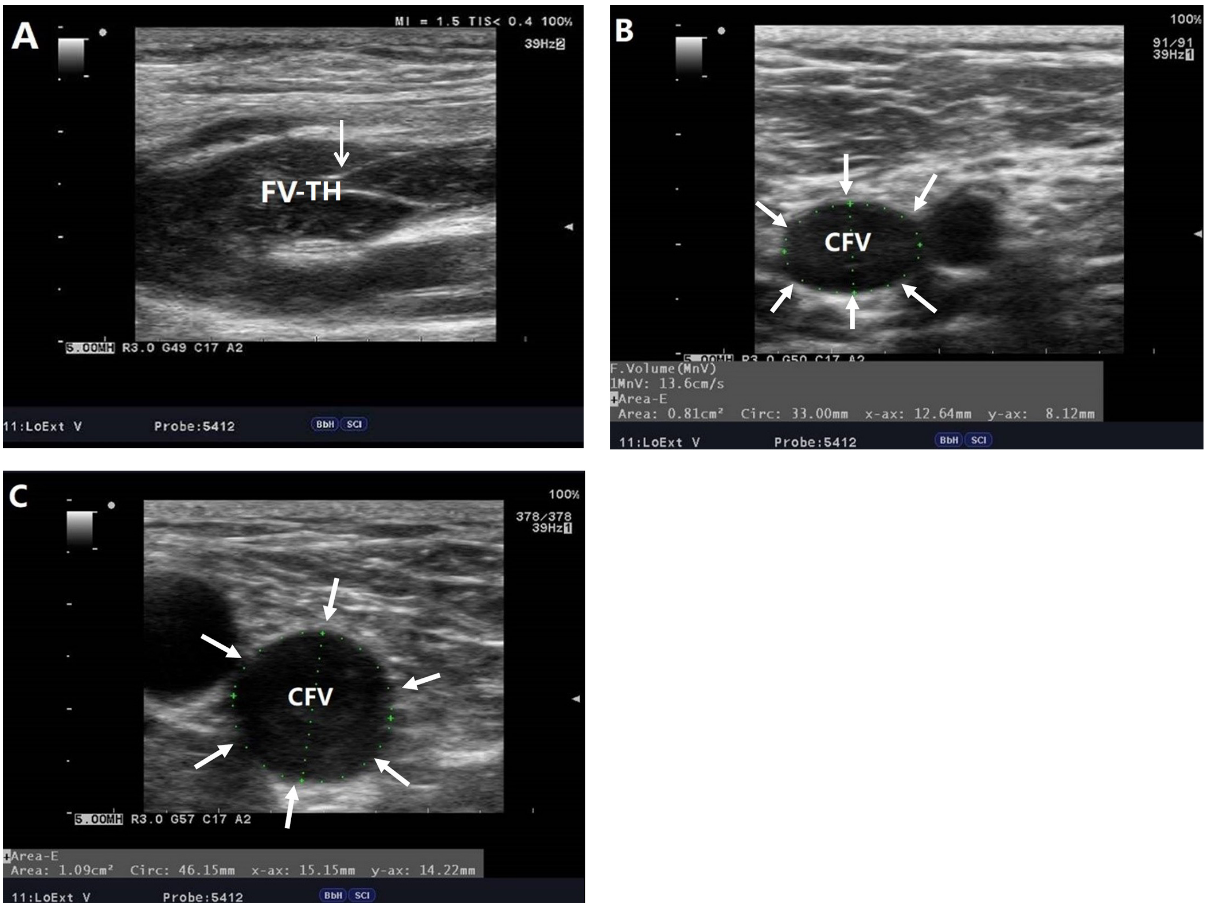

Fig. 1. Ultrasonic image of deep vein of lower extremity. (A) The femoral vein was completely filled with thrombosis (FV-TH, femoral vein thrombosis), and the thrombus wrapped the venous valve (As the white arrow shows). (B,C) Perimeter (C) and area (A) values were traced along the intimal side of the cross-section of middle CFV (green dotted line as shown by the white arrows, CFV, common femoral vein). (B) In the Non-deep venous thrombosis (DVT) group, before surgery, CFV cross-sectional perimeter C = 33.0 mm, cross-sectional area A = 81.0 mm^2, C^2/A=13.4. (C) In the DVT group, before surgery, CFV cross-sectional perimeter C = 46.15 mm, cross-sectional area A = 109.0 mm^2, C^2/A = 19.5.

val (CI): 0.888–0.972, $p < 0.001$), 0.937 (95% CI: 0.886–0.970, $p < 0.001$), and 0.917 (95% CI: 0.861–0.956, $p < 0.001$), respectively. Furthermore, CFV-C^2/A, FV-C^2/A, and POV-C^2/A demonstrated sensitivities of 91.7%, 94.6%, and 91.9%, while the specificities of 97.4%, 95.6%, and 93.8%, respectively.

Among the clinical and surgical parameters, the Caprini score, and tourniquet use time exhibited higher predictive value for DVT, with ROC cutoff values >2, and 0.9 h, respectively. The AUC were 0.844 (95% CI: 0.776–0.899, $p < 0.001$) and 0.869 (95% CI: 0.805–0.919, $p < 0.001$) for the Caprini score and tourniquet use time, respectively. Furthermore, the Caprini scores and tourniquet use time showed a sensitivity of 91.9% and 78.4%, while a specificity of 64.3% and 90.3%, respectively (Table 3, Fig. 2).

ROC Curve Analysis of Parameter Predicting DVT

In the pairwise comparison of ROC curves for hemodynamic parameters predicting DVT, the CFV-C^2/A ratio exhibited a significant differences compared to CFV-C, CFV blood flow, and CFV Inner diameter (all $p < 0.05$). Similarly, there was significant difference between the FV-C^2/A ratio and FV-C ($p < 0.001$), and no significant difference between FV-C^2/A and FV blood flow ($p > 0.05$). The POV-C^2/A ratios were significantly different from POV-C, POV-A, and POV blood flow (all $p < 0.05$).

In the clinical parameters, significant differences were observed between the Caprini score and age or C-reactive protein (all $p < 0.05$). In contrast, no significant differences were observed between the Caprini score and BMI or D-dimer (all $p > 0.05$). Among the surgical parameters, tourniquet application time demonstrated significant differences compared to operation type, operation time, and bed-time (all $p < 0.05$) (Table 4).

Combining the Caprini Score with C^2/A to Predict DVT

The AUCs for predicting DVT in orthopedic patients utilizing the Caprini score >2 combined with CFV-C^2/A, FV-C^2/A, and POV-C^2/A were 0.953 (95% CI: 0.905–0.981, $p < 0.001$), 0.965 (95% CI: 0.922–0.988, $p < 0.001$), and

Table 1. Comparison of general clinical data between the DVT and non-DVT groups.

Variable	DVT group (n = 37)	Non-DVT group (n = 113)	χ^2	*p*-value
Age (Y)				
$<$50	2 (5.4)	48 (42.5)	17.239	$<$0.001
$\geq$50	35 (94.6)	65 (57.5)		
Sex				
Male (%)	15 (40.5)	54 (47.8)	0.589	0.443
Female (%)	22 (59.5)	59 (52.2)		
BMI (Kg/m^2)				
$<$25	10 (27.0)	69 (61.1)	12.952	$<$0.001
$\geq$25	27 (73.0)	44 (38.9)		
Hypertension				
No (%)	27 (73.0)	76 (67.3)	0.423	0.515
Yes (%)	10 (27.0)	37 (32.7)		
Coronary artery disease				
No (%)	33 (89.2)	101 (89.4)	0.000*	1.000
Yes (%)	4 (10.8)	12 (10.6)		
Diabetes mellitus				
No (%)	33 (89.2)	99 (87.6)	0.000*	1.000
Yes (%)	4 (10.8)	14 (12.4)		
Blood type				
Type A (%)	10 (27.0)	37 (32.7)		
Type B (%)	10 (27.0)	29 (25.7)	1.888	0.596
Type AB (%)	2 (5.4)	12 (10.6)		
Type O (%)	15 (40.6)	35 (31.0)		
C-reactive protein (mg/L)				
$<$8	26 (70.3)	96 (85.0)	3.959	0.047
$\geq$8	11 (29.7)	17 (15.0)		
Platelet count (10^9/L)				
$<$300	30 (81.1)	105 (92.9)	3.125*	0.077
$\geq$300	7 (18.9)	8 (7.1)		
D-dimer (mg/L)				
$<$0.6	7 (18.9)	69 (61.1)	19.805	$<$0.001
$\geq$0.6	30 (81.1)	44 (38.9)		
Caprini score				
$\leq$2	3 (8.1)	73 (64.6)	35.590	$<$0.001
$>$2	34 (91.9)	40 (35.4)		
Type of surgery				
Non-joint arthroplasty (%)	11 (29.7)	66 (58.4)	9.176	0.002
Hip and knee arthroplasty (%)	26 (70.3)	47 (41.6)		
Operation time (h)				
$<$2	4 (10.8)	48 (42.5)	12.341	$<$0.001
$\geq$2	33 (89.2)	65 (57.5)		
Tourniquet use time (h)				
$<$1	8 (21.6)	104 (92.0)	73.061	$<$0.001
$\geq$1	29 (78.4)	9 (8.0)		
Bed time (d)				
$<$3	16 (43.2)	77 (68.1)	7.334	0.007
$\geq$3	21 (56.8)	36 (31.9)		

Note: *The chi-square correction test was used for numerical statistics. BMI, body mass index; DVT, deep venous thrombosis. $p < 0.05$ was considered statistically significant.

Table 2. Comparison of ultrasonic parameters between the DVT and non-DVT groups.

Variable	DVT group (n = 37)	Non-DVT group (n = 113)	*t/Z*	*p*-value
CFV inner diameter (mm)	11.25 ± 1.42	10.36 ± 1.29	3.567	0.001
CFV flow rate (cm/s)	18.69 ± 6.98	19.55 ± 7.52	0.610	0.543
CFV blood flow (mL/min)	613.05 ± 177.50	683.21 ± 136.65	2.509	0.013
CFV-C (mm)	43.93 ± 4.83	38.04 ± 3.84	7.586	<0.001
CFV-A (mm^2)	109.03 ± 25.91	99.47 ± 17.81	2.512	0.013
CFV-C^2/A	18.82 ± 1.39	14.77 ± 1.34	15.833	<0.001
FV inner diameter (mm)	6.97 ± 1.34	6.54 ± 1.15	1.874	0.063
FV flow rate (cm/s)	14.22 ± 6.05	15.14 ± 6.88	0.727	0.469
FV blood flow (mL/min)	147.75 ± 61.69	261.32 ± 92.82	6.949	<0.001
FV-C (mm)	35.14 ± 4.51	31.65 ± 3.99	4.471	<0.001
FV-A (mm^2)	67.16 ± 16.81	70.03 ± 17.38	0.878	0.381
FV-C^2/A	18.81 ± 1.55	15.33 ± 1.13	14.732	<0.001
POV inner diameter (mm)	6.78 ± 1.57	6.94 ± 1.30	0.616	0.539
POV flow rate (cm/s)	8.55 (4.92)	8.45 (5.22)	0.488	0.625
POV blood flow (mL/min)	114.55 ± 50.54	156.38 ± 48.47	4.509	<0.001
POV-C (mm)	35.94 ± 3.37	34.26 ± 2.44	3.279	0.001
POV-A (mm^2)	68.91 ± 12.69	77.63 ± 11.29	3.951	<0.001
POV-C^2/A	18.90 ± 1.94	15.30 ± 1.30	12.873	<0.001

Note: CFV, common femoral vein; FV, femoral vein; POV, popliteal vein; C, venous cross-sectional perimeter; A, venous cross-sectional area. $p < 0.05$ was considered statistically significant.

Table 3. Receiver operating characteristic (ROC) curve analysis of each parameter predicting DVT.

Groups	Cutoff value	YI	Sensitivity (%)	Specificity (%)	AUC (95% CI)	*p*-value
CFV inner diameter (mm)	>11.3	0.338	56.8	77.0	0.681 (0.600–0.755)	0.001
CFV blood flow (mL/min)	<512.0	0.325	40.5	92.0	0.622 (0.540–0.700)	0.039
CFV-C (mm)	>43.0	0.435	54.1	89.4	0.764 (0.688–0.829)	<0.001
CFV-A (mm^2)	>127.4	0.118	16.2	95.6	0.513 (0.430–0.595)	0.825
CFV-C^2/A	>17.4	0.891	91.7	97.4	0.939 (0.888–0.972)	<0.001
FV blood flow (mL/min)	<158.0	0.570	70.3	86.7	0.854 (0.788–0.907)	<0.001
FV-C (mm)	>35.8	0.363	48.7	87.6	0.695 (0.615–0.768)	<0.001
FV-C^2/A	>17.1	0.902	94.6	95.6	0.937 (0.886–0.970)	<0.001
POV blood flow (mL/min)	<118.5	0.437	67.6	76.1	0.741 (0.663–0.809)	<0.001
POV-C (mm)	>36.0	0.302	51.4	78.8	0.645 (0.562–0.721)	0.016
POV-A (mm^2)	>69.0	0.292	48.7	80.5	0.686 (0.605–0.759)	<0.001
POV-C^2/A	>17.0	0.857	91.9	93.8	0.917 (0.861–0.956)	<0.001
Age (Y)	>50.5	0.379	91.9	46.0	0.738 (0.660–0.806)	<0.001
BMI (Kg/m^2)	>26.1	0.454	64.9	80.5	0.742 (0.664–0.810)	<0.001
C-reactive protein (mg/L)	>6.2	0.218	43.2	78.6	0.619 (0.536–0.697)	0.023
Caprini score	>2.0	0.562	91.9	64.3	0.844 (0.776–0.899)	<0.001
D-dimer (mg/L)	>2.1	0.642	75.7	88.5	0.834 (0.765–0.890)	<0.001
Type of operation	—	0.518	73.0	78.8	0.759 (0.682–0.825)	<0.001
Operation time (h)	>2.0	0.334	86.5	46.9	0.688 (0.608–0.762)	<0.001
Use time of tourniquet (h)	>0.9	0.687	78.4	90.3	0.869 (0.805–0.919)	<0.001
Bed rest time (d)	>2.5	0.249	56.8	68.1	0.675 (0.594–0.749)	<0.001

Note: C, venous cross-sectional perimeter; A, venous cross-sectional area; AUC, area under curve; YI, Youden index. $p < 0.05$ was considered statistically significant.

0.948 (95% CI: 0.900–0.978, $p < 0.001$), respectively. They showed the sensitivities of 94.6%, 97.3%, and 89.2%, while the specificities of 90.3%, 92.9%, and 92.0%, respectively (Table 5, Fig. 3).

Furthermore, there were significant differences between the combined parameters and the Caprini score (all $p < 0.05$) compared to the Caprini score alone (Table 5). This resulted in improved sensitivity, specificity, positive predic-

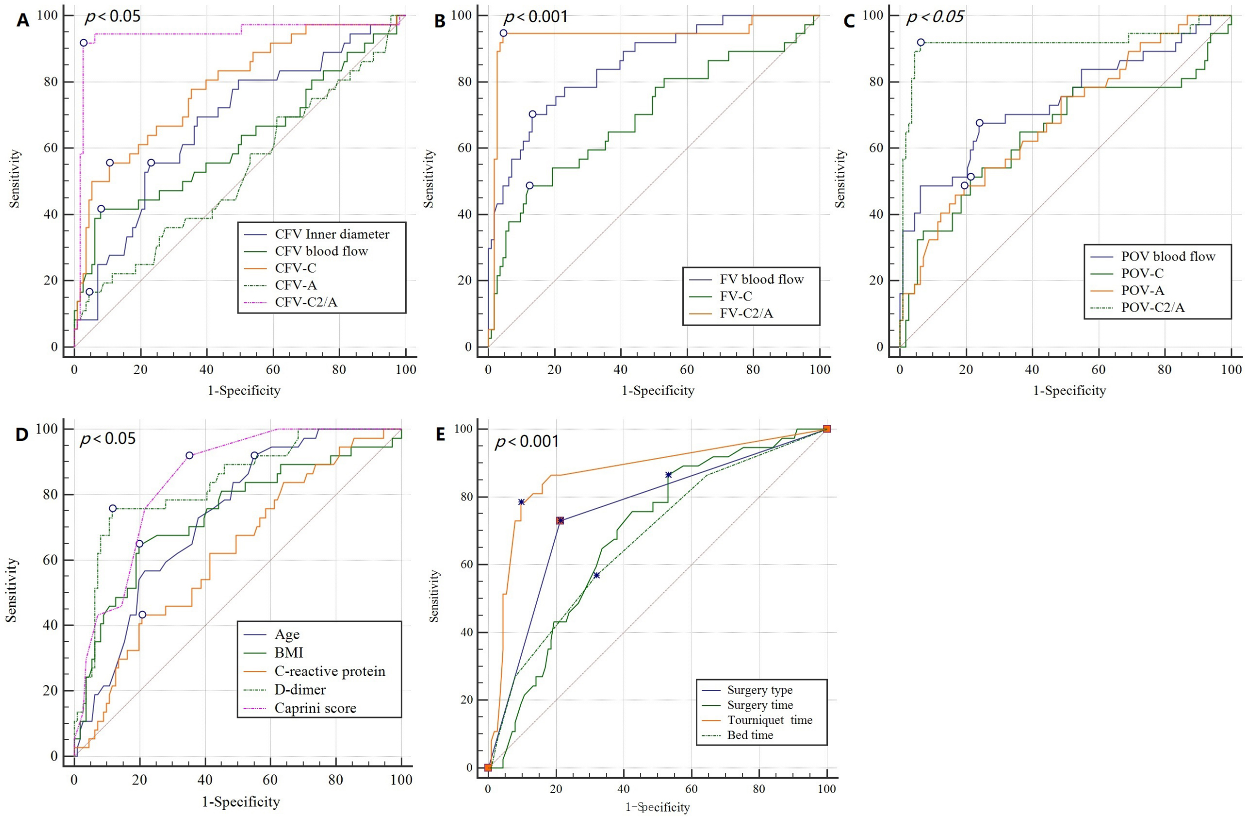

Fig. 2. ROC curve of each parameter to predict DVT. ROC curve represented all parameters ((A–C) were ultrasound parameters; (D) were clinical parameters; (E) were surgical factors) in predicting the risk of DVT in orthopedic patients after surgery. (A) CFV-C^2/A showed significantly higher predictive value for DVT, with ROC cutoff values >17.4 amongst CFV ultrasonic parameters. (B) FV-C^2/A had the highest predictive value for DVT, with ROC cutoff values >17.1 amongst FV ultrasonic parameters. (C) POV-C^2/A had the highest predictive value for DVT, with ROC cutoff values >17.0 amongst POV ultrasonic parameters. (D) The Caprini score demonstrated a higher predictive value for DVT, with ROC cutoff values >2 amongst clinical parameters. (E) Time of tourniquet had the highest predictive value for DVT, with ROC cutoff values >0.9 h amongst surgery parameters. (C, venous cross-sectional perimeter; A, venous cross-sectional area).

Table 4. ROC curve of parameter predicting DVT pairwise comparison.

Groups	Difference in AUC	SE	95% CI	*Z*	*p*-value
CFV-C^2/A ~ CFV-C	0.175	0.058	0.057–0.282	2.950	0.003
CFV-C^2/A ~ CFV blood flow	0.317	0.055	0.214–0.430	5.834	<0.001
CFV-C^2/A ~ CFV inner diameter	0.258	0.054	0.146–0.360	4.651	<0.001
FV-C^2/A ~ FV blood flow	0.083	0.049	–0.009–0.183	1.780	0.075
FV-C^2/A ~ FV-C	0.242	0.050	0.135–0.330	4.669	<0.001
POV-C^2/A ~ POV-C	0.272	0.072	0.139–0.420	3.894	0.000
POV-C^2/A ~ POV-A	0.231	0.065	0.104–0.356	3.564	0.000
POV-C^2/A ~ POV blood flow	0.176	0.054	0.066–0.276	3.190	0.001
Caprini score ~ Age	0.106	0.049	0.013–0.205	2.229	0.026
Caprini score ~ BMI	0.102	0.065	–0.022–0.231	1.621	0.105
Caprini score ~ C-reactive protein	0.225	0.057	0.111–0.334	3.915	0.000
Caprini score ~ D-dimer	0.010	0.049	–0.086–0.107	0.213	0.831
Use time of tourniquet ~ Type of operation	0.110	0.044	0.019–0.192	2.388	0.017
Use time of tourniquet ~ Operation time	0.181	0.066	0.052–0.310	2.750	0.006
Use time of tourniquet ~ Bed rest time	0.194	0.061	0.075–0.314	3.186	0.001

Note: C, venous cross-sectional perimeter; A, venous cross-sectional area; SE, standard error; CI, confidence interval. $p < 0.05$ was considered statistically significant.

Table 5. The Caprini score combined with C^2/A to predict DVT.

Groups	Cutoff value	YI	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	AUC (95% CI)	p-value
Caprini score-CFV-C^2/A	>0.24	0.849	94.6	90.3	76.1	98.1	0.953 (0.905–0.981)★	<0.001
Caprini score-FV-C^2/A	>0.23	0.902	97.3	92.9	81.8	99.1	0.965 (0.922–0.988)★	<0.001
Caprini score-POV-C^2/A	>0.25	0.812	89.2	92.0	78.6	96.3	0.948 (0.900–0.978)★	<0.001
Caprini score	>2.00	0.562	91.9	64.3	45.9	96.1	0.844 (0.776–0.899)	<0.001

Note: ★ indicated that there was a statistical difference between the joint parameters and the Caprini score alone. C, venous cross-sectional perimeter; A, venous cross-sectional area. $p < 0.05$ was considered statistically significant.

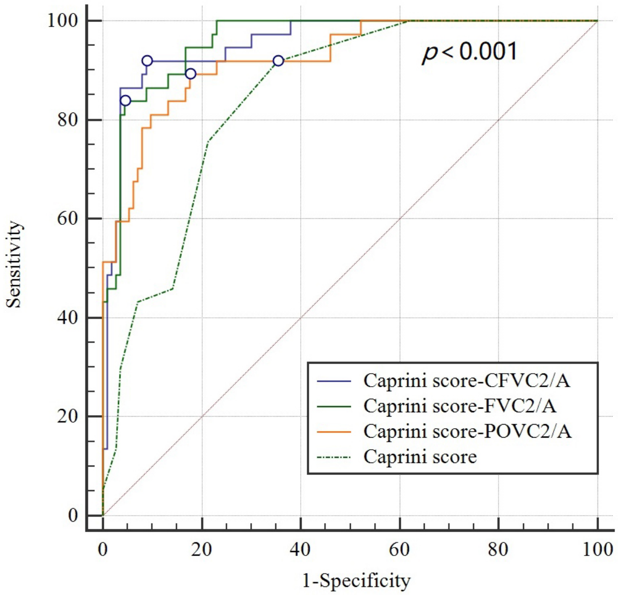

Fig. 3. ROC curve of the Caprini score combined with C^2/A to predict DVT. When the Caprini score of >2 combined with C^2/A (CFV, FV, and POV), the AUC, specificity, positive predictive value, and negative predictive value for predicting DVT in orthopedic patients was higher than Caprini score.

tive value, and negative predictive value for DVT when combining C^2/A with the Caprini score. Interestingly, the combination of the Caprini score with FV-C^2/A exhibited the highest statistical value.

Discussion

Accurate identification and prompt intervention are crucial for preventing DVT in perioperative orthopedic patients with surgery. In our study, patients who underwent lower limb orthopedic surgery were included, which affects the venous hemodynamics of the lower limbs. The incidence of DVT during hospitalization after surgery was 24.7%. Furthermore, this study revealed several factors with significant predictive value of postoperative DVT in orthopedic patients, such as age >50.5 years, IBM >26.1, C-reactive protein >6.2 mg/L, Caprini score >2, D-dimer >2.1 mg/L, type of operation, operation time >2 hours, tourniquet use time >0.9 hours, and bed rest time >2.5 days. These results underscore the significance of improved preventive management for perioperative VTE when these risk factors are observed. Among them, tourniquet use time >0.9 h had the highest predictive value. While tourniquet usage effectively reduces bleeding during surgery and provides a clear surgical field, long-term use of tourniquet can cause tissue ischemia, hypoxia, ischemia-reperfusion injury, and vascular endothelial damage, ultimately disrupting blood flow and elevating the risk of DVT. One study reported that patients in the tourniquet group exhibited higher levels of thrombin-antithrombin III complex, D-dimer, and neutrophil elastase in their blood compared to those in the non-tourniquet group [32]. Physicians should be aware of the potential risks associated with lower extremity tourniquet use, especially in patients with recent trauma. The combined effect of trauma and tourniquet use can substantially increase the risk of developing deep vein thrombosis in the lower extremities and associated complications.

The Caprini score is often used preoperatively to assess DVT risk. The Chinese guideline for VTE prevention recommends its application for assessing VTE risk in orthopedic surgery patients [9]. However, in the clinical setting, the risk classification provided by the Caprini score may need additional clarification. A retrospective study of 974 postoperative patients with gynecological tumors for 3 years observed that 87.6% of the patients had a Caprini score ≥5. Patients with a Caprini score >7 showed 11.9 times higher incidence of VTE than those with scores between 5 and 7. Therefore, researchers suggested separating scores >7 from 5–7 and combining them with D-dimer levels for enhanced VTE risk stratification [33]. Additionally, a retrospective study conducted on 419 pediatric orthopedic patients revealed that the Caprini score was not effective in identifying high-risk hospitalized children for DVT, indicating a sensitivity of 0.0% and specificity of 99.8% for the Caprini scores ≥11 [34]. Conversely, our study revealed that a Caprini score >2 increased DVT risk, with an AUC of 0.844 and sensitivity and negative predictive value of 91.9% and 96.1%, respectively. However, the specificity and positive predictive value were reduced at 64.3% and 45.9%. The lower-than-expected specificity and positive predictive value may limit the Caprini score's predictive ability in orthopedic patients. Therefore, our study envisaged combining the Caprini score with ultrasound parameters to further enhance its predictive value.

Previous study has reported that a preoperative soleus vein (SV) diameter of ≥10 mm significantly increases DVT risk after hip and knee replacement surgeries (OR: 6.67). SV exceeding 10 mm has been found as an independent predictor of DVT following major orthopedic surgeries [35]. Furthermore, another study indicated significant differences in posterior tibial vein flow velocity in 91 patients undergoing knee arthroplasty across four simulated operative positions (full extension 0°, semiflexion 30–60°, flexion 90°, and maximal flexion 90°+). The lower average flow velocity was found in the simulated position (90°+). Patients with flow velocity lower than 10 cm/s exhibited a 21.6% higher relative risk of DVT [36].

Furthermore, this study observed that, apart from a statistically significant difference in the diameter of CFV between the thrombosis and non-thrombosis groups, no significant differences were found in the diameters of the femoral vein FV and POV or the flow velocities of CFV, FV, and POV. This difference may be attributed to the use of foot pressure pumps by orthopedic inpatients. This device increases the blood volume in the proximal veins by compressing the distal limbs, leading to significant changes in the diameters and flow velocities of CFV, FV, and POV. A previous study has reported that foot pressure pumps can immediately change the mean blood flow velocity and volume in the lower extremity veins of orthopedic patients after surgery [37]. After 20 minutes of use, these indices stabilize within a certain range, and 40 minutes after discontinuation, they return to near-before use levels. This finding is helpful for accurately evaluating and effectively correcting the effect of foot pressure pumps on ultrasound indexes of lower extremity venous in clinical practice.

The present study aimed to identify a new ultrasound parameter to improve early DVT prediction. Theoretically, if a vein's cross-section is perfectly circular, the ratio of the square of the circumference to the area (C^2/A) would be $C^2/A = (2\pi r^2)/(\pi r^2) = 4\pi$, eliminating the influence of the vessel diameter and resulting in a constant value. When the vein lumen deforms, the actual measurement deviates from this constant. The greater the deviation, the more severe the deformation and the greater the venous filling degree. In this study, parameters were computed to predict DVT in orthopedic inpatients following surgery. Among these, the C^2/A for CFV, FV, and POV proved effective in predicting DVT. The findings indicated that the C^2/A ratios in the thrombosis group were higher than those in the non-thrombosis group. Moreover, the C^2/A of the thrombosis group deviated more significantly from the constant 4π, indicating that greater preoperative venous deformation is associated with a higher risk of postoperative DVT in orthopedic patients. In contrast with conventional ultrasound parameters such as vein diameter and flow velocity, the new ultrasound parameter C^2/A shows higher predictive value for DVT, fewer interference factors, and offers a more intuitive description of changes in the vein lumen. The result showed that combining the Caprini score with the ratio of the cross-sectional perimeter^2 (C^2) /area (A) of lower extremity veins (CFV, FV, POV) significantly improved the specificity and positive predictive value for DVT prediction, especially with the FV-C^2/A (AUC 0.965, specificity 92.9%, positive predictive value 81.8%). Combining the Caprini score with the C^2/A ratio further enhances the predictive value in orthopedic surgery patients and could contribute to more robust VTE prophylactic. Additionally, timely ultrasound monitoring may help in early DVT identification, and enable timely treatment to reduce the incidence of post-thrombotic syndrome and fatal PE. We suggest modifying the Caprini score to add ultrasound parameters like the C^2/A ratio, combining both methods to evaluate the risk of postoperative VTE in patients. In the future, we plan to train a model utilizing supervised learning to automatically identify abnormal data points and trends based on labeled normal and abnormal data samples. By setting a reasonable threshold, this strategy could offer new methods and tools for improving the prevention and management of thrombus in patients after orthopedics surgery.

Despite some promising findings, this study has the following limitations: (1) the small sample size and the lack of data on PE during the short study period, which may cause some bias into the results. Future investigations will aim to expand the sample size to obtain more reliable and accurate results; (2) some patients were unable to fully abduct their lower limbs during ultrasound due to posture limitation, which may have impacted sonographic measurement. For example, some patients with lower limb fractures could be placed in the standard external rotation and abduction position, resulting in slight pressure from the probe during ultrasound examination, causing minor deformation of the lower limb veins and affecting measurement accuracy. To reduce this error, we recommend using a high-resolution probe to improve the image clarity and averaging multiple measurements; (3) the heterogeneity in the types of orthopedic surgeries performed may pose challenges in statistical analysis. Future studies should perform subgroup analysis or stratified studies of large clinical trials to reduce errors associated with the heterogeneity of surgical types.

Conclusions

In conclusion, the new ultrasound venous filling degree parameter of the C^2/A ratio exhibits a higher predictive value for DVT. Compared to conventional ultrasound parameters, the C^2/A ratio is less impacted by external factors and offers a more intuitive description of changes in the lumen of lower limb veins. Furthermore, combining the Caprini score with the C^2/A ratio improves the predictive accuracy for DVT occurrence in orthopedic surgery patients. This combination may provide new insights for the early clinical prevention of DVT.

Availability of Data and Materials

The data generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

Conception and design: XC, SJT, YWC and LWL; Analysis and interpretation: XC, SJT; Data collection: XC, LA, FG, FT, MY; Writing the article: XC, YWC and LWL; Obtained funding: LWL; Overall responsibility: LWL. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study had been approved by the Ethics Committee of the First Affiliated Hospital of the Air Force Medical University (KY20232031-F-1). Informed consent was obtained from all participants. The study design followed the ethical guidelines of the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of interest.

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